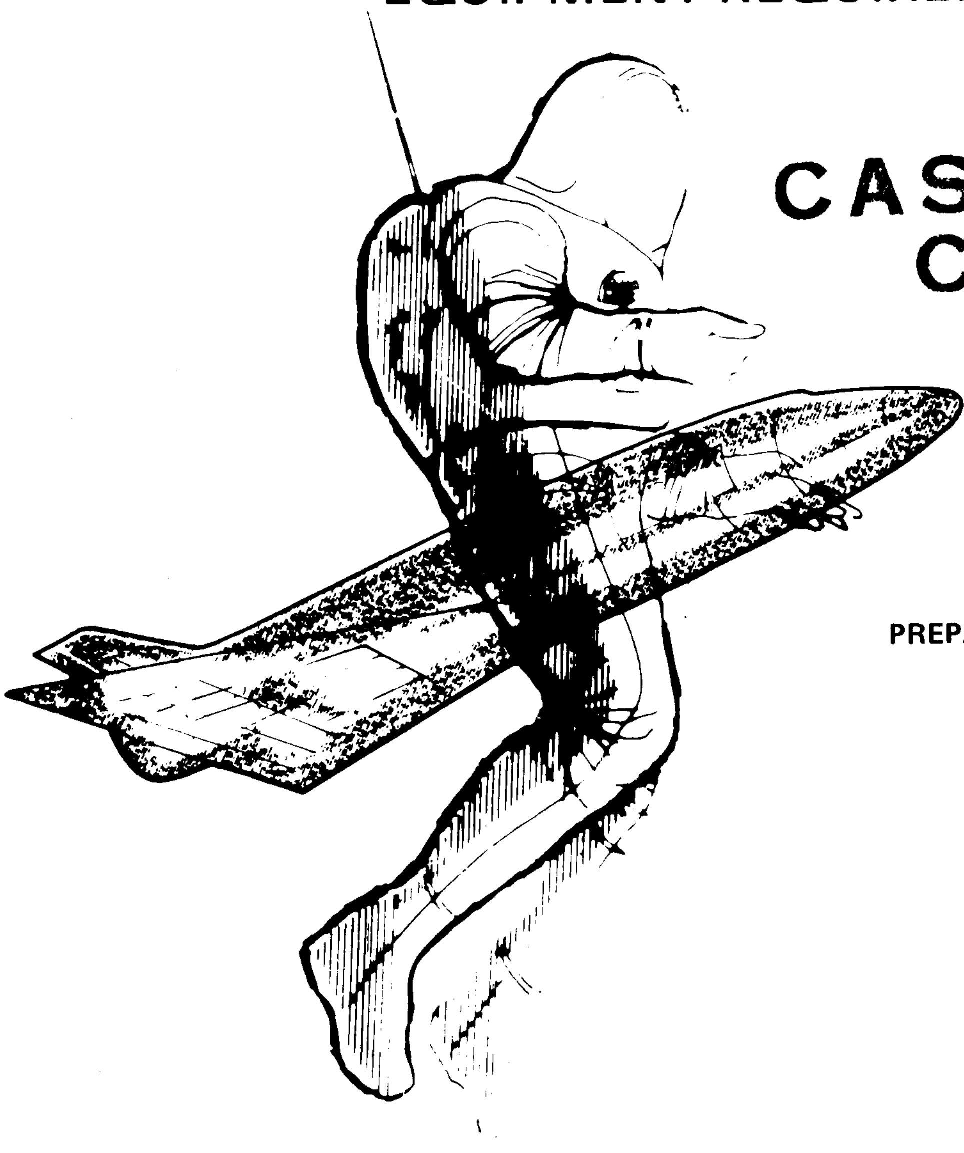
SP 01T73
VOLUME II

CR-128942

N73-24876

SPACE SHUTTLE EVA/IVA SUPPORT EQUIPMENT REQUIREMENTS STUDY



(APPENDIX)
FINAL SUMMARY REPORT
PREPARED UNDER NASA CONTRACT
NO. NAS 9-12506

SP 01T73
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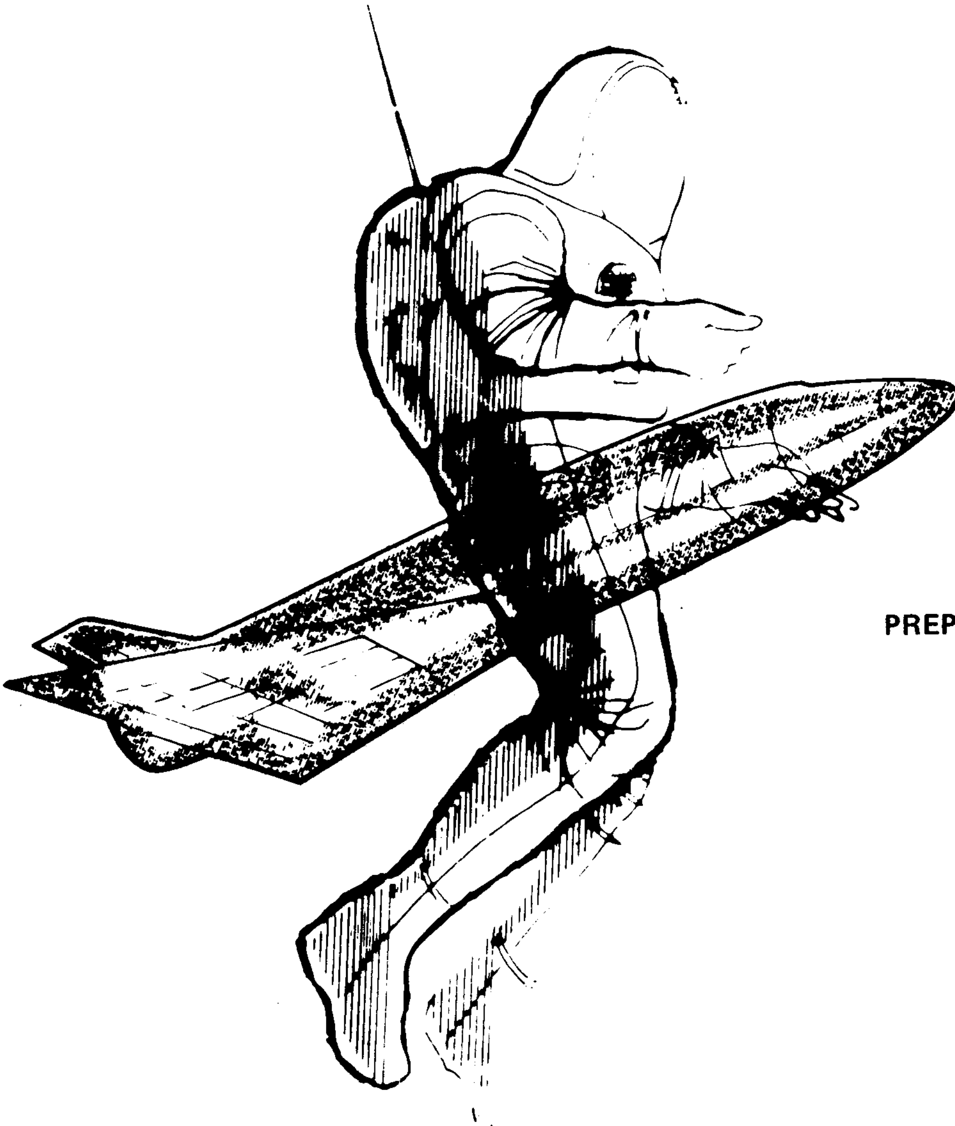
SPACE SHUTTLE EVA/IVA SUPPORT EQUIPMENT REQUIREMENTS STUDY



(APPENDIX)
FINAL SUMMARY REPORT
PREPARED UNDER NASA CONTRACT
NO. NAS 9-12506

APRIL 30, 1973

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

FOREWORD

This is the Appendix for the Final Summary Report of the "Shuttle EVA/IVA Support Requirements Study". This effort was conducted by Hamilton Standard under NASA Contract NAS 9-12506 for the Lyndon B. Johnson Space Center of the National Aeronautics & Space Administration from March 14, 1972 to April 30, 1973. The principal contributors to this effort are listed in alphabetical order below:

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Special thanks are due to the Technical Contract Monitor, Mr. Donald Boydston, Crew Systems Division of the NASA Lyndon B. Johnson Space Center, for his advice and guidance.

This total report is contained in two (2) volumes as listed below:

Volume I	Final Summary Report
Volume II	Appendix

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APPENDIX A

SHUTTLE EVA/IVA TASK IDENTIFICATION AND ANALYSIS

The potential planned EVA tasks associated with each payload on each NASA Shuttle flight, as defined by the March 21, 1972 Traffic Model, were identified in Hamilton Standard Engineering Memorandum Number NA-SVA-0002, dated July 11, 1972. In addition, this memorandum also identified potential unscheduled and emergency EVA tasks associated with Shuttle flights. As the study progressed, the information contained in this memorandum was updated and transferred to work sheets. These work sheets are contained in Sections 1.0, 2.0 and 3.0 of this Appendix and form the basis for the results presented in Section 4.0, Volume I.

A large number of the planned Shuttle missions during the 1979 - 1990 period might be utilized to either retrieve or service satellites which are presently operating in orbit or have been deactivated or become dormant. The potential for these type of operations are discussed in Section 4.0.

The sensitivity of Shuttle payloads to contamination is also a major factor in the EVA/IVA task identification and analysis effort. Section 5.0 contains a study of payload contamination sensitivity of all the payloads listed in the March 21, 1972 NASA/DOD Shuttle Traffic Model.

SECTION 1.0

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF. A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM **	LSS CANDIDATES: SELF CONT SYSTEM
	Revisit(s) HEAO, LST, LSO, LRO	Yes	X	X	X		EVA:															
							Star Trackers (aft/forw.)				=	<	=		67/unit		40/65	Yes	Yes	Yes	Yes /No	Yes
							•Clean		1													
							•Align		1													
							•Calibrate	10	1	600												
							•Inspect		1													
							•Replace	25	1	1000-1400				Restraints, Tools, Lighting								
							Magnetometers				=	<	=		17		40	Yes	Yes	Yes	Yes	
							•Replace	25	1	1000-1200				Restraints, Tools, Lighting								
							•Calibrate	10	1	600												
							•Inspect		1													
							Wide Angle Sun Sensor				=	<	=		2		35-57	No	Yes	Yes	Yes	Yes
							•Inspect															
							•Clean															
							•Align															
							•Calibrate	5	1	600												
							•Replace	10	1	900												

D – DEPLOYMENT OF SATELLITES, KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETREIVAL OF SATELLITES, OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS
*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (i.e.; suit is <, =, > to the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only.

** ASSUMING PROVISIONS ARE AVAILABLE FOR PROPER UMBILICAL MANAGEMENT

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	Revisit Cont.						RCS Thruster Mod.				=	<	>		10-55		35	Yes	Yes	Yes	Yes	Yes
							•Inspect															
							•Reposition															
							•Replace	30	1	1000-1200				Restraints, Tools, Lighting								
							Antenna				=	<	=		25-40		57	No	Yes	Yes	Yes	Yes
							•Reposition															
							•Replace	15	1	1000												
							Cryogenics System				>	=	=				30	Yes.	Yes	Yes	Yes	Yes
							•Refuel	5	1	800				Restraints, Tools, Lighting	30							
							Propellant Refuel	5	1	800	>	=	=	Restraints, Tools, Lighting			30	Yes	Yes	Yes	Yes	Yes
							Optical Contam. Detect.				<	<	=	Restraints, Tools, Lighting			70	Yes	Yes	No	No	Yes
							•Inspect															
							•Replace	30	1	12-1600												

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							Solar Array Panel(s)				=	<	=		40-50							
							•Clean															
							•Inspect															
							•Replace	30	1	1000 1200				Restraints, Tools			45-56	No	Yes	Yes	Yes	Yes
							Secondary Mirror Drive Motor				=	<	=		10		65'	Yes	Yes	No	No	Yes
							•Inspect															
							•Replace	20	1	1000-1100												

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FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	MISSION FUNCTIONS R	MISSION FUNCTIONS S	MISSION FUNCTIONS E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	TASK ASSESSMENT: NO. OF MEN REQUIRED	TASK ASSESSMENT: METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	SUIT REQUIREMENTS REF. A7LB: DEXTERITY	SUIT REQUIREMENTS REF. A7LB: VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	SUPPORT EQUIPMENT REQUIRED: WT	SUPPORT EQUIPMENT REQUIRED: VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	TRANSLATION CANDIDATES: HAND RAILS	TRANSLATION CANDIDATES: MANEUVERING UNITS	TRANSLATION CANDIDATES: MANIPULATOR	LSS CANDI-DATES: UMBILICAL SYSTEM	LSS CANDI-DATES: SELF CONT SYSTEM
							Deploy/Retract Sortie Can Radiator	20	1/2	800-1100	=	<	>				30'	No	Yes	Yes	Yes	Yes	
							Calibration/Operate Monitor Equipment (IV Mode)		1	600-1000	=	<	>				25'	Yes	No	No	Yes	Yes	

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	General Applications Research Module		X			X	Thermal Coating Refurbishment in Space *				>	<	>				∠60'	Yes	Yes	Yes	Yes	Yes
							• Data Acquisition	5/Read	1	800-850				Portable Spectroreflec., camera	8	648 cu"						
							• Photograph Exposure Plates/Refurb. Oper.	5/Item	1/2	750					10-15							
							• Refurbish coating	10/ Item	1	750-800	< >			Cleaning (ACD), painting, vacuum deposition tools and adhesives and applicators	5-10	4 cu" /Plate						
							• Visual Inspection and Commentary	continuous	1													
							Leak Detection and Repair				>	<	>				40'	Yes	Yes	Yes	Yes	Yes
							• Data Acquisition	15	1	800-850				Leak detector (Quadrapole type)	3-10	1728 cu"						
							• Employ Repair Techniques	20	1	750-800	<			Application of Sealant (viscous fluids and self adhesive patches)	10	1728						
							Maintainable Attitude Control Propulsion System				>	<	>				25'	Yes	Yes	Yes	Yes	Yes
							• Connect/Disconnect Video/Photographic Equipment	10	1	900-1000				Vehicle mounting provisions, recepticles and feed-through line	20-25							
							• Connect/Disconnect Power Lines	2	1	800												
							• Close/Open Propellant Feed Lines	5	1	850												

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

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							• Replace/Reinsert Assembly and/or components (thrusters regul, valves)	15-25	1	1000-1200	>			Tools (wrenches, etc.)	100		25'	Yes	Yes	Yes	Yes	Yes
							Ball Bearing Lubrication				>	<	>				<60'	Yes	Yes	Yes	Yes	Yes
							• Mount/Disassemble Test Assembly	10	1	900-1000					251bs	5184 cu"						
							• Connect/Disconnect Power and Instrumentation Lines	2	1	800												
							• Seal Assembly in Protective container	5/unit		850-900					5-10							
							Space Exposure Effects On Material Bulk* Properties				>	<	>				<60'	Yes	Yes	Yes	Yes	Yes
							• Mount/Disassemble Assembly	20	2	1000-1200				Coatings, Plastics, Composits, Lubricants elastomers, etc.	150	8640 cu"						
							• Sample Retrieval/Replace	10	1	900-1000					0.15/sample							

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* Utilizing extended on-orbit stay time free flying vehicle periodically revisited by the shuttle

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	General Applications Research Module						Space Exposure Effects on Mat. Bulk Prop. Cont.				>	<	>				<60'	Yes	Yes	Yes	Yes	Yes
							• Place in airlock/ glove chamber	5/unit	1	750-800												
							• Seal in Containers	5/item	1	850-900					50							
							• Stow	5/item	1	1000												
			X	X		X	Advanced Guidance** Subsystems Evaluation (IVA)				<	<	>				25'	Yes	No	No	Yes	Yes
							• Ingress/Egress Free Fly Module	2	1	900												
							• Install/Remove Experimental Systems	45	1	900-1000				Gyroscopic Test Package	50	5184 cu"						
							• Checkout Equipment	15	1	600-700				Accelerometer Package	30	1728 cu"						
							• Connect/Disconnect Test Apparatus to Digital Data Acquisition system on free flyer	10	1	800-900				Three Axis Table (Installed in free fly module)								
							Space Exposure Effects On Material Fatigue Properties*				=	<	>				<60	Yes	Yes	Yes	Yes	Yes
							• Mount/Disassemble Fatigue Specimen Fixture	10	1	900-1000					2-5							
							• Retrieve Specimen(s)	5/unit	1	900-1000					0.06/unit	11cu"/unit						

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** Utilizing a free-flying Module (such as the Astronomy Ram) as a test bed

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	GARM (cont.)						• Place in/Retrieve from airlock/ glove chamber	5/unit	1	750-800	=	<	>				<60	Yes	Yes	Yes	Yes	Yes
							• Package Specimen (Subsequent to tests) in vacuum tight container	5/unit	1	850-900					20lbs for 100 units	3100cu"						
							• Stow	5/unit	1	1000												

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	General Scientific Research Mod.	No (Except as Noted)	X			X	Surface Degradation Experiment				=	<	>									
							•Install/Disassemble Exposure Racks	25	1	900-1000												
							•Place Exposure Strips Into Racks	15	1	800				Restraints, Clamps	5/rack (4 req'd)	384 in^3/rack	35'	Yes	Yes	Yes	Yes	Yes
							•Install Quartz Crystal Contam. Gage	20	1	1000												
							•Engage Power Lines	2	1	800				Vehicle Receptacle	0.5	6 in^3 unit						
							•Data Acquisition - Portable Spectro-reflectometer (P.S.)	5/read	1	800-850					8 lbs	648 in^3						
							•Retrieve Exposure Strips	20	1	800						1.44 /strip 45 in^3 cont.						
							•Place in Protective Containers	20	1	850-900					0.5 lbs cont. (30) req'd							
							•Backfill Protective Containers (Argon)	5-10	1	800				Receptacles, Lines, Instrumentation and Gas Source								
							•Stowage	13	1	1000												

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	General Scientific Research Mod. Cont.						Active Cleaning Technique Evaluation				>	<	>		10lbs	3340 cu"							
							•Data Acquisition (P.S.)	5/read	1	800-850				Portable Spectro-reflectometer	8lbs.	648cu	"70'	Yes	Yes	No	No	Yes	
							•Clean Items (Radiator Surfaces, windows, lenses)	5/item	1	900	=			Active cleaning device									
							Contamination Control Evaluation				=	<	>										
							•Mount/Disassemble Test Panel	10	1	900-1000				Test Panel	20lbs	108cu	35'	Yes	Yes	Yes	Yes	Yes	
							•Engage/Disengage Power and Gas Lines	2	1	800				Vehicle Recepticles									
							Contaminant Dispersal Measurements				=	<	>										
							•Mount/Disassemble High Resolution Camera (Television and Pictures)	25	1	900-1100				Mounting Provisions for controlled pan and tilt head	25lbs each 2reqd	3360 cu" stowed	50-100	Yes	** Yes	No	*** Yes	Yes	
							•Replace/Retrieve Film Cassettes	10	1	900-1000				Vehicle Recepticles	4 lbs each	48cu" each							
							•Engage/Disengage Lines	2	1	800													

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** Can be employed as a method of obtaining improved view angles or accessibility
*** Not applicable if maneuvering unit or work platforms are employed at the longer distance

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	General Scientific Research Module Continued						Contaminant Cloud •Composition Measurement				=	<	>				50'	Yes	Yes	Yes	Yes	Yes	
							•Attach/Detatch Mass Spec. Sensor Head	10	1	900-950				Clamps, Vehicle Hardmounts	2lbs/unit 2 req.	72cu"Sensor							
							•Engage/Disengage Lines	2	1	800				Vehicle Recepticle									
							Integrated Real-Time Contamination Monitor				=	<	>										
							•Attach/Detach IRTCM (OpFM)	20	1	1000-1100				Vehicle Hardmount previsions for optical properties evaluating modules vehicle recepticle	22lbs	1728 cu"	25-30	Yes	Yes	Yes	Yes	Yes	
							•Engage/Disengage Utilities (lines)	2	1	800													
							•Retrieve IRTCM Sample Trays	10	1	800-850													
							•Place in Transit Cases	5	1	800-850													
							•Stowage	5	1	1000													
							Real Time Contamination Measurements				=	<	>										
							•Attach/Detach Contam. Gage (Quartz crystal)	5/unit	1	1000				Mounting Provisions	0.5/gage 16 reqd.	6cu" unit	30	Yes	Yes	Yes	Yes	Yes	
							•Engage/Disengage electrical lines and instrumentation cables	2	1	800				Vehicle recepticles									
							•Place in Protective containers	30	1	800-900					5/each 4 req.	480 cu"/case							

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
	General Scientific Research Module Con't.						•Backfill Protective Containers	10	1	800	=	<	>	Recepticles, Gas Source, Lines and Instrumentation			30	Yes	Yes	Yes	Yes	Yes
							•Stowage															
		Partially					Sky Background Brightness Measurements								25lbs	3920 cu" stow-ed	50	Yes	Yes	Yes	Yes	Yes
							•Deploy/Retrieve Polarimeter assembly	15	1	900-1000				Mounting Provisions								
							•Engage/Disengage Power Lines	2	1	800				Vehicle Recepticle								

D – DEPLOYMENT OF SATELLITES, KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETREIVAL OF SATELLITES, OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

SP 01T73

SSD--PC--64

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

								TASK ASSESSMENT			SUIT REQUIREMENTS REF. A7LB			SUPPORT EQUIPMENT REQUIRED			TRANSLATION CANDIDATES					LSS CANDI-DATES
FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	MOBILITY	DEXTERITY	VISIBILITY	DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	SELF CONT SYSTEM
	Dedicated Science and Research Module - Astronomy (P/L No. 40)	Yes					Similar to Astronomy Payload P/L No. 44															

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SSD-PC-64

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS				PLANNED TASKS	TASK ASSESSMENT			SUIT REQUIREMENTS REF. A7LB			SUPPORT EQUIPMENT REQUIRED			TRANSLATION CANDIDATES					LSS CANDIDATES	
			D	R	S	E		TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	MOBILITY	DEXTERITY	VISIBILITY	DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	SELF CONT SYSTEM
	Dedicated Applications Module - E.0	No	X			X	Similar to Earth Observation Payload No. 42																

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SP 01T73

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	MISSION FUNCTIONS R	MISSION FUNCTIONS S	MISSION FUNCTIONS E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	TASK ASSESSMENT: NO. OF MEN REQUIRED	TASK ASSESSMENT: METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	SUIT REQUIREMENTS REF. A7LB: DEXTERITY	SUIT REQUIREMENTS REF. A7LB: VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	SUPPORT EQUIPMENT REQUIRED: WT	SUPPORT EQUIPMENT REQUIRED: VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	TRANSLATION CANDIDATES: HAND RAILS	TRANSLATION CANDIDATES: MANEUVERING UNITS	TRANSLATION CANDIDATES: MANIPULATOR	TRANSLATION CANDIDATES: UMBILICAL SYSTEM	LSS CANDI-DATES: SELF CONT SYSTEM
	Earth Observation Lab	No	X			X	Task similiar to P/L No. 41. See 1984 Flt. Nos. 23-24 to be performed by Space Station Crew																

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF. A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
	Earth Observation	No					Remove Lens Cover From Observation Telescope	10	1		>	<	>		2-5		40'	Yes	Yes	Yes	Yes	Yes	
							Replace Film Cassette	10	1	900-1000	>	=	>				30	Yes	Yes	Yes	Yes	Yes	

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*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (i.e.; suit is <, =, >, to the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only.

Data Sources: GDCA RAM Study
Preliminary Mass Prop
Document Vol. V, Pg. 4-17

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF. A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
	Astronomy GDCA P/L No. A881X	Mode-rate	X			X	Release Gimbals (2) Locks	5	1	800-900	=	=	>				60'	Yes	Yes	Yes	Yes	Yes
							Load Film Cassettes into Cameras	10	1	900-1000		=	>		5-12		**					
							Load Cameras & Retectors into instrument	20	1	900-1100		<	>				**					
							Open Hatch Cover	5	1	800		=	>									
							Change Film Cassettes and/or detectors	10	1	900-1000		=	>									

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** Tasks could be performed in IVA Mode

*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (i.e.; suit is <, =, > to the task requirements)
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*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only.

SP 01T73

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
	Astronomy GDCA P/L No. A651B	yes [a]					Remove Protective Covers & Stow	10	1	900-1000	=						37'	Yes	Yes	Yes	Yes	No H_2O Dump	
							Inspect for Damage		1	600-700													
							Release Launch Locks From Gimbals	5	1	800-900													
	Start of Experiment						Measure Contamination Levels	5/min readout	1	800-850				Portable Spectro-reflectometer	8	648 in3	37'						
	Close-Out						Retrieve Protective Covers & Replace	10	1	900-1000	=												
							Secure Gimbals	5	1	800-900													
							Verify Sortie can secure for Reoribt	20	1	600-800													

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(a) Telexcopes cooled to less than 15°K.

Data From: Blue Book, Vol II Para 6.0
GDCA RAM Study Prel. Mass Prop. Document App. V pg. V-2

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

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	Astronomy GDCA P/L No. A8S1W	(a)					Release Launch Locks From Gimbals (2)	5	1	800-900	=	<	>				60'	Yes	Yes	Yes	Yes	Yes	
							Remove Lens Covers	10	1	900-1000													
							Change Film Cassettes	10	1	900-1000													
							Focus & Align Telescope Calibrate Instrument	1hr.	1	600-700	<						IVA	Yes	-	-		Yes	

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(a) Wide field uv Telescope Sensitivity to Contamination is described as moderate There is no sub cooling of lens.

(b) Gamma-Ray Spectrometer Sensitivity to Contaminations is described as slight. - Radiation Sensitivity/ Must be less than 1.0 millirad/hr.

Data obtained from: Blue Book, Vol. II parag. 4.4-4.7
GDCA RAM Study, Prel. Mass Prop
Document App. V, Pg. V-4

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

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	AMU	No	X	X		X	AMU Evaluation															
							- Unstow	10	1	1000							<60'	Yes	No	Yes	No	Yes
							- Check Condition	5-10	1	600-700												
							- AMU Checkout	15	1	600-700												
							- Donning	10	2	700-900												
							A. Tether Mode															
							Secure Tethers	2	1	800-900							A/R	No	Yes	No	No	Yes
							Manage Tether**	As req'd	1	600-800												
							Fly out of P/L Bay	As req'd	1	700												
							Stabilize															
							Translate to End of Tether (200 ft.)															
							Return to Orbiter (Fwd)															
							Station Keep															
							Perform Maneuvers (i.e., around orbiter)															
							Dock at Work Platform															

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** To be performed by second crewman.

SP 01T73

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

SSD--PC-64

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDI-DATES: SELF CONT SYSTEM
	AMU Cont.						Perform Various Tasks	As req'd	1	700				Fastening Equipment			A/R	No	Yes	No	No	Yes
							Translate 100 ft. Behind Orbiter															
							Induce External Force															
							Evaluate Recovery															
							Return to Orbiter	As req'd	1	700												
							Release Tether **	2	1	800-900							60'	Yes	No	Yes	Yes	Yes
							Restow Tether	5	1	1000												
							Deactuate AMU Stow.	20	1	800-1000												
							B. Untethered Mode															
							Fly out of P/L Bay	As req'd	1	700							A/R	No	Yes	No	No	Yes
							Stabilize															
							Translate 200 ft. from orbiter															
							Return															
							Station Keep															
							Perform Maneuvers (Fly around orbiter)															
							Dock at Work Platform															
							Remove 200 LB Mass from work platform	10	1	800-1000												

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** Performed by Second Crewman

SP 01T73

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

SSD–PC–64

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS: D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
	AMU Cont.						Attach to suit or AMU	5	1	1000-1200							A/R	No	Yes	No	No	Yes
							• Translate 200 ft. from orbiter &	As Reqd.	1	700												
							• Return to Work Platform	As Reqd.	1	700												
							• Secure 200 lb mass to Work platform	5	1	1000-1200												
							• Fly 100 ft. from Orbiter	As Reqd.	1	700												
							• Induce External Force		1													
							• Evaluate Recovery		1													
							• Return to Orbiter via Non-direct route		1													
							• Dock in Payload Bay		1													
							• Deactivate AMU		1													
							• Stowage	10	1	1000												
							AMU Operations (All Modes				=	<	>				N/A					
							• Operate Hand Controls	As Reqd.	1	700												
							• Observe & Monitor Instrumentation	As Reqd.	1	600-800												

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	AMU cont.						AMU Serivicing				>	=	>				60'	Yes	No	Yes	Yes	Yes
							•Cold Gas [b] Resupply	3	-	700-800												
							•Replace Bottles	20	1	900-1100				Replacement Bottles	18#	13" Dia Sphere						
							•Recharge															
							-Connect/Disconnect Umbilicals	2	1	800												
							-Operate Valves	1/ Valve As Reqd.	1	700												
							•Verify Resupply Completion		1	600-800												
							-Gages Readings															
							•Remove & Install Film Cassettes	10	1	900-1000				60 Minutes of Film per cassette								
		No	X	X	X	X	•Recharge Battery															
							•Connect/Disconnect Cables	2	1	800												
							•Monitor Instr.	5	1	600-800												
							•Operate Switches	~	1	600-800												

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b Resupply of cold gas (O_2 @ 6000 p ia) can be accomplished by recharge or bottle replacement

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	Maneuvering Work Platform	No	X	X	X	X	MWP Evaluation				=	<	>				<60'	Yes	HHMO Only	Yes	Yes	Yes	
							• Ingress P/L Bay	2	1	900													
							• Unstow MWP	15	2	1000													
							• Deploy Running Board, Antenna & Etc.	15	2	750-900								NA	NA	NA			
							• Mount Control Station	1	1	600													
							• Secure Restraints	1	1	700													
							• Check out & Activate Subsystems																
							• Operate Switches	15	1	600-700													
							• Read Displays																
							• CMG Spin-Up																
							Close Proximity Maneuvers	As Req'd		700	=	<	>				A/R				No	Yes	
							• Fly out of P/L Bay																
							• Stabilize																
							• Translate 200 ft. behind orbiter																
							• Station Keep																
							• Maintain Attitude																
							• Return to Orbiter Via Prescribed Velocity & Attitude																

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
		No	X	X	X	X	Close Proximity Maneuvers (Cont.)				=	<	>				<60'	No	No	No	No	Yes
							• Dock at B/C Work Platform	As Req'd		700												
							• Operate Tools			700-800	<											
							• Drilling															
							• Cutting															
							• Joining															
							• Make Connection (Electr. & Fluid)			800	=											
							• Assemble Items			900-1000												
							• Separate & Translate 100 ft. behind orbiter			700							A/R					
							• Induce External Force															
							• Evaluate Recovery															
							• Return to Orbiter															
							• Dock to Orbiter using Fwd Grapplers										<60'					
							• Attach Cargo Bed (Pip Pins)			900-1000												
							• Place 500 LB Mass on MWP & Secure			700-1000												
							• Undock & Fly Out of P/L Bay			700							A/R					

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SSD--PC--64

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	MISSION FUNCTIONS R	MISSION FUNCTIONS S	MISSION FUNCTIONS E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	TASK ASSESSMENT: NO. OF MEN REQUIRED	TASK ASSESSMENT: METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	SUIT REQUIREMENTS REF. A7LB: DEXTERITY	SUIT REQUIREMENTS REF. A7LB: VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	SUPPORT EQUIPMENT REQUIRED: WT	SUPPORT EQUIPMENT REQUIRED: VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	TRANSLATION CANDIDATES: MANEUVERING UNITS	TRANSLATION CANDIDATES: MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							Close Proximity Maneuvers (Cont.)				=	<	>									
							• Stabilize	As Reqd.	1	700							A/R	No	No	No	No	Yes
							• Translate 200ft. behind orbiter															
							• Station Keep															
							• Induce External Force															
							• Evaluate Recofery															
							• Translate to Orbiter															
							• Dock Using fwd. Crapplers															
							• Remove 500 lb mass & Secure in P/L Bay			700-1000												
							• Remove Cargo Bed & Stow			900-1000												
							• Shut Down MWP Sub-Systems			600-700												
							Experiment Complete															

D – DEPLOYMENT OF SATELLITES, KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETREIVAL OF SATELLITES, OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS				PLANNED TASKS	TASK ASSESSMENT			SUIT REQUIREMENTS REF. A7LB			SUPPORT EQUIPMENT REQUIRED			TRANSLATION CANDIDATES					LSS CANDI-DATES
			D	R	S	E		TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	MOBILITY	DEXTERITY	VISIBILITY	DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	SELF CONT SYSTEM
		No	X	X	X	X	Remote Maneuvers				=	<	>				As Reqd.	No	No	No	No	Yes
							• Fly out of P/L Bay	As Reqd.	1	700												
							• Stabilize															
							• Translate 2 Km Behind orbiter															
							• Station Keep															
							• Fly around an object															
							• Fly back to Orbiter with maneuvers & attitude changes															
							• Dock at work platform using fwd. grapplers.															
							• Attach Cargo Bed (Pip pins)			900-1000												
							• Place 500 lb Mass on MWP & Secure			700-1000												
							• Undock			700												
							• Fly out of P/L Bay															
							• Translate 2 Km from Orbiter															
							• Return to Orbiter															
							• Dock to Orbiter															
							• Shut down subsystems			600-700												

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SP 01T73

SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
		No	X	X	X	X	Remote Maneuvers - cont.				=	<	>				As Reqd.	No	No	No	No	Yes
							• Remove 500 lb mass, Stow & Secure	10	1	900-1000												
							• Stow MWP	20	1	900-1000												
							Rescue Demonstration				=	<	>									
							• Translate out of P/L Bay	As Reqd.	1	700												
							• Stabilize															
							• Translate to Stranded MWP															
							• Dock to Stranded MWP															
							• Transfer to Stranded MWP	1	1	800	<											
							• Release Stranded crewman restraint	2	1	900												
							• Transfer Crewmen to Cargo Bed & restrain	5		900-1000												
							• Undock from Stranded MWP.	As Reqd.		700												
							• Fly back to orbiter				=											
							• Dock MWP															
							• Remove crewman	5	1	900-1000												
							• Place Crewman in Airlock	5	1	900-1000												

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SHUTTLE EVA/IVA PLANNED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	PLANNED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF. A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
		No	X	X	X	X	Rescue Demonstration (Cont.)				=						As Reqd.	No	No	No	No	Yes
							Deliver Crewman Back to "Stranded" MWP & Terminate Experiment															
		No	X	X	X	X	MWP Servicing				=	=	>				<60'	Yes	Yes	Yes	Yes	Yes
							Refueling															
							• Connect Umbilicals	2	1	800												
							• Operate Valves	1/Unit	1	700												
							• Monitor Instrumentation	5	1	600-800												
							Battery Charging				=	=	>									
							• Connect Cables	2	1	800												
							• Operate Switches		1	600-800												
							• Monitor Instr.	5	1	600-800												

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

SECTION 2.0

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
	Payload Deployment Manipulator (I)		X				A. Inspection of malfunctioned Item, Photograph	5-10	1	600-700	=	=	>				<60'	Yes	No	No	Yes	Yes
							B. Payload Doors (and Radiator) fails to open				<	<	=				<60'	Yes	No	No	Yes	Yes
							•Inspection (see above)															
							•Release door latch mechanisms	10	1	1000-1100												
							•Lubricate Mechanisms	5	1	750-800				Lubricant and applicator								
							•Extract Rotating Mechanism and/or Drive Motor	20-25	1	900-1100												
							•Repair/Reinstall															
							•Remove Appendages			800-1000				General Repair Kit								
							•Perform Manual Deployment Procedures	15	2	900-1200				Crank								
							**•If mission abort req'd connect umbilicals and instrument. Initiate de-fuel sequence of payload (incl. kickstage)	5	1	800												
							C. Manipulator Tiedowns Fail to Release (caution light indicat.)				<	<	>				< 60'	Yes	No	No	Yes	Yes

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
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** OPERATIONAL SEQUENCE OF MISSION MAY NEGATE THIS TASK AS DISENGAGEMENT MAY BE REQUIRED AT A SUBSEQUENT TIME.

*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (i.e.; suit is <, =, >, the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only.

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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SSD–PC–65

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							C. (continued)				=	<	>				< 60	Yes	No	No	Yes	Yes
							•Inspection															
							•Repair Captive Latches (unlocking)	15	1	1000-1100	<			General Repair Kit								
							•Operate Manual Override Provisions	5	1	800-900				General Repair Kit								
							•Deburr and Lubricate Latches			750-1000				General Repair Kit, Lubricant and Applicator								
							•Checkout Force Feedback Sensors and automatic release circuitry	10	1	600-700												
							D. Video Camera Fails				=	<	>				<60'	Yes	No	No	Yes	Yes
							•Verify Lens Cover Removed															
							•Electrical Continuity Check	10	1	600-700												
							•Remove/Install Auxilliary Payload Bay Camera	25	1	900-1100	<											
							E. Payload Restraints Fail to Release (caution light indication)				<	<	>				<60'	Yes	No	No	Yes	Yes
							•Similar to Manip. Tiedown Failure (C)															

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SSD-PC-65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	MOBILITY	SUIT REQUIREMENTS REF A7LB: DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							F. Manipulator Fails to align with Payload Attachment Points				=	<	>				<60'	Yes	No	No	Yes	Yes
							•Provide Supplemental Lighting	5	1	600-700				Light Source								
							•Readjust Video Orientation and Docking Aid	10	1	600-700												
							•Assist Manipulator to Establish Proper Alignment		1	600-800	<											
							•Provide Guidance Instructions	5	1	-	=											
							•Provide Force to Damp Oscillations in Boom		1	600-800	<											
							G. Manipulator Fails to Engage Payload Attachments (caution light)				=	<	>				<60'	Yes	No	No	Yes	Yes
							•Provide Supplemental Force to Engage Payload	2	1	700-900												
							•Deburr and Lubricate Interfacing Elements			750-1000				General Repair Kit, Lubricant and Applicator								
							•Replace End Effectors	15	1	900-1100	<											

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SSD–PC–65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							G. (continued)				<	<	>				<60'	Yes	No	No	Yes	Yes	
							•Verify Attachment Integrity (apply force equal to translation maneuvers magnitude)	2	1	750-900													
							•Checkout Touch Sensor Feedback and Circuitry	10	1	600-700													
							H. Manipulator's Failure to raise Payload				<	<	>				<60'	Yes	Yes	No	Yes	Yes	
							•Drive Motor Failure																
							•Assist Manupulator by providing supplemental force	15	2	700-900													
							•Replace Drive Motor	20	1	900-1200													
							I. Manipulator(s) Inoperable (2 crewmen)				<	<	>				<60'	Yes	Yes	No	Yes	Yes	
							•Unstow Deployment Tools/Aids	10	1	1000				Deployment Tools									
							•Restrain/Secure	5	1	700													
							•Attach Deployment Mechanism (1 crewman)	10	1	750-850													
							•Remove Protective Covers	5	1	600-700	<												

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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SSD–PC–65

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS: D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							I. (continued)				<	<	>				60	Yes	Yes	No	Yes	Yes
							•Release Payload Tie-downs (uncock if required)	10	1	800-900												
							•Disconnect Service/ Monitoring Umbilicals	5	1	800												
							•Extend Payload	15	2	900-1200												
							•Release Payload	5	2	700-800												
							•Retract Mechanism	10	2	600-700												
							•Stow Equipment	10	1	1000												
							J. Manipulator Fails to Disengage Payload				<	<	>				75'	Yes	Yes	No	No	Yes
							•Translate to Worksite	10	1	700-900	=											
							•Inspection															
							•Manually Release at Attachment Point	10	1	800-900	<											
							•Remove End Effector	15	1	800-1000												

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SSD—PC—65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							K. Manipulator Fails to Retract Following Payload Deployment				<	<	>				<60'	Yes	Yes	No	Yes	Yes	
							•Apply supplemental forces to boom	10	1	750-900													
							•Apply lubrication to Main Interface Joint	5	1	750-800				Lubricant and Applicator									
							•If possible after retraction, replace drive motor, checkout circuitry	30	1	600-1200								Yes					
							L. Manipulator Fails to align with the Tie-downs				<	<	>				<60'	Yes	No	No	Yes	Yes	
							•Manually Guide Manipulator into position	5	1	600-800													
							M. Manipulator Tiedowns fail to secure (caution light)				<						<60'	Yes	No	No	Yes	Yes	
							•Similar to Previously noted failure of Tiedowns to release (C)																
							•Provide alternate means of restraint	10	1	750-900				Nylon cord, etc.									

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SSD—PC—65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDI-DATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
	Payload Deployment Pivot Mechanism (II)						A. Release Mechanism (Payload)				<	<	>				<60'	Yes	No	No	Yes	Yes
							•Same as release mechanism stated for manipulator (E)															
							B. Pivot Mechanism Failure				<	<	=				30'	Yes	No	Yes	Yes	Yes
							•Inspection															
							•Lubricate and Remove Appendages			750-1000				General Repair Kit Lubricant and Applicator								
							•Repair/Replace Electrical Drive Motor	20	1	900-1200												
							•Manually crank table (and Payload) into errect position (90°, detent)	15	2	900-1200				Crank								
							•Disconnect payload from pivot mechanism and attach to manipulator to exercise task	15	2	800-1000												
							a) Conduct experiment (sortie) in IV mode															
							b) Connect support umbilicals and lines	10		800												

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SSD—PC—65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	MISSION FUNCTIONS R	MISSION FUNCTIONS S	MISSION FUNCTIONS E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	TASK ASSESSMENT: NO. OF MEN REQUIRED	TASK ASSESSMENT: METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	SUIT REQUIREMENTS REF A7LB: DEXTERITY	SUIT REQUIREMENTS REF A7LB: VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	SUPPORT EQUIPMENT REQUIRED: WT	SUPPORT EQUIPMENT REQUIRED: VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	TRANSLATION CANDIDATES: HAND RAILS	TRANSLATION CANDIDATES: MANEUVERING UNITS	TRANSLATION CANDIDATES: MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							C. Expandable Tunnel is not pressurizable				<	<	=				20'	Yes	No	No	Yes	Yes	
							•Leak Detection	30	1	800-850				Quadrapole Leak Det.	3-10	1728 in^3							
							•Replace Faulty Valves	30	1	800-1000													
							•Repair Tunnel Structure	30	1	800-900				Sealant or Weld Kit	10 lbs	1728 in^3							
							•Accomplish Mission objectives in IV mode																

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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SSD—PC—65

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS *I REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
	Payload Retrieval Direct Dock (I) (Service, Maint. and Return)						A. All Malfunctions				=	=	>				< 60'	No	Yes	Yes	Yes	Yes
							•Inspection															
							•Photograph	5-10	1	600-700												
							B. Docking Adapter Anomaly (failure to expose)				<	<	>									
							•Failure of Pivot Mechanism							See Deployment (IIB) Direct dock to forward section. A consideration Breathing Adapter may be required per Payload design.								
							•Inspection															
							•Repair of Mechanism															
							•Payload Bay Doors Fail to Open (see Deploy IB)										< 60	Yes	No	No	Yes	Yes
							•Visual Aids are Damaged, Misaligned										20'	Yes	Yes	Yes	Yes	Yes
							•Replace/Realign Aids	15	1	800-900												
							•Provide Guidance Instruction															
							•Inability To Establish Hard Dock															
							•Inspection of Interface															
							•Lubricate, Remove Appendage		1	750-1000				General Repair Kit, Lubricant and Applicator								

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E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS
*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (i.e.; suit is <, =, > to the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							•Repair Captive Latches	15	1	1000-1100	<	<	>	General Repair Kit									
							•Checkout Sensor and Circuitry	10	1	600-700													
							•Transfer Equipment to Payload	120	2	900-1400							20'	No	Yes	Yes	Yes	Yes	
							•Conduct Service/Maint. as required (See Revisit)	240	2	700-1200													
							•Conduct Retrieval Manually with Deploy/ Retrieval Mechanisms (similar to deploy II)																
	Payload Retrieval Manipulator Capture and Dock (S & M) (II)						Payload Doors fail to open (see Deploy. IC)				<	<	>										
							Video Camera Fails (see Deploy. ID)																
							Manip. Fails to Engage Payload Attachment (see Deploy. IG)																
							Manip. Fails to Align with P/L Attachment (see Deploy. IF)																
							Manip. Fails to Align Payload with Adapter																
							Manually guide payload into proper orientation.	5	1	600-800							<50'	Yes	Yes	Yes	Yes	Yes	
							Docking System Anomaly (see direct Dock retrieval IB)																

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS
*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (I.E.; suit is <, =, > to the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
*IV Defines head enclosure requirements, only.

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SSD—PC—65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
	Payload Retrieval Return to Earth Manipulator (III)						Manipulator Inoperable Similar to Deploy. (II)				<	<	>										
							Inability to Align Payload with Restraints Similar to Deploy. (IL)																
							Payload Tiedowns Fail to Secure (caution light) Similar to Deploy (IC)																
							Manipulator Fails to Disengage Payload see Deploy. (IJ)																
							Manipulator Fails to Retract subsequent to Payload Retrieval see Deploy. (IK)																
							Manipulator Tiedowns do not engage (or caution light) Similar to Deploy (IC)				>	<	>										

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
14,16 18,20	Revisit Missions HEAO, LST, LSO, LRO						EVA: Repair/Replace (if applicable to specific observatory)				<	<	>										
	(Free Flying Astronomical Observatories)						•Light Shield	40	1	800-900							<75'	Yes	Yes	No	No	Yes	
							•Light Shield Actuator Motor(s)	20	1	900-1100							<75'	Yes	Yes	No	No	Yes	
							•Electromechanical Drive for Solar Array Orientation	20	1	900-1100					5		50'	Yes	Yes	Yes	Yes	Yes	
							•Docking Adapter (see retrieval)										20'	No	Yes	Yes	Yes	Yes	
		Yes					•Deployable Pressure Domes and Protective Covers	10	1	700-800							75'	Yes	Yes	No	No	Yes	
		Yes					•Aperature Doors/Motors Rotating Members										75'	Yes	Yes	No	No	Yes	
							Lubricate & Deburr			750-1000													
							Force Application			750-900													
							Replace Items (motors, etc.)			900-1100													
							Repair/Deploy/Stow Thermal Protective Cover	10	1	800-1000							20'	No	Yes	Yes	Yes	Yes	
							Repair/Replace/Restrain Electromagnetic Torque Bar	5-15	1	700-900							20'	Yes	Yes	Yes	Yes	Yes	

D – DEPLOYMENT OF SATELLITES, KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETREIVAL OF SATELLITES, OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

*I Criteria defines capability of the A7LB suit assembly to accomplish the associated task (I.e.; suit is <,=,> to the task requirements)
*II Defines man/suit requirements excluding gloves and head enclosure
*III Defines glove requirements, only.
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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: *II MOBILITY	*III DEXTERITY	*IV VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							IVA:															
							Replace (failure or update)/Repair Instrumentation	15-30	1/2	800-1200	<	<	=									
							•Photoheliograph								** <4600	1900 ft^3	36'	Yes	No	No	Yes	Yes
							•Spectrograph/Spectroheliograph								<1100	150 ft^3	36'	Yes	No	No	Yes	Yes
							•Ultraviolet Telescope										36'	Yes	No	No	Yes	Yes
							•Ultraviolet Spectroheliograph										36'	Yes	No	No	Yes	Yes
							•Coronagraph								** <995	60 ft^3	36'	Yes	No	No	Yes	Yes
							•Extreme UV Spectroheliograph								** <995	216 ft^3	36'	Yes	No	No	Yes	Yes
							•X-Ray Spectroheliograph										36'	Yes	No	No	Yes	Yes
							•Crystal Spectroheliograph										36'	Yes	No	No	Yes	Yes
							•Flare Detector										36'	Yes	No	No	Yes	Yes
							•High Energy X-Ray Collimator								6-30 lbs		36'	Yes	No	No	Yes	Yes
							•Large area and Solid State Detector										36'	Yes	No	No	Yes	Yes
							•High Resolution Crystal Spectrometer										36'	Yes	No	No	Yes	Yes
							•Proportional Counter Array								196	9.7 ft^3	36'	Yes	No	No	Yes	Yes

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

** Replaceable Portions
Photoheliograph: Support Instrumentation 200 lbs.
- Experiments - 1100 lbs.
UV Spectroheliograph - 80 lbs.
Coronograph - 132 lbs.

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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							IVA: (continued)																
							•Scintillation Counter Array				<	<	=		318	8 ft^3	36'	Yes	No	No	Yes	Yes	
							•Low Energy X-Ray Detector								400	7.2 ft^3	36'	Yes	No	No	Yes	Yes	
							•Super Conducting Magnet										36'	Yes	No	No	Yes	Yes	
							•IR Spectrograph										36'	Yes	No	No	Yes	Yes	
							•Photoelectric Radiometer										36'	Yes	No	No	Yes	Yes	
							•Vector Magnetograph										36'	Yes	No	No	Yes	Yes	
							•Longitudinal Field Magnetograph								66		36'	Yes	No	No	Yes	Yes	
							•Electronic Detection Devices								110		36'	Yes	No	No	Yes	Yes	
							Calibrate/Align/Checkout of Instrumentation	6-26 hrs	2	600-800							36'	Yes	No	No	Yes	Yes	
							Replenish Consumables	1-4 hrs	1		=	<	>		83-1000		36'	Yes	No	No	Yes	Yes	
							Repair/Replace:				<												
							Tape Recorders	15	1	800-1000					5-40 lbs		36'	Yes	No	No	Yes	Yes	
							Remote Acquisition Units	20-30	1	800-1000					10 lbs/item		36'	Yes	No	No	Yes	Yes	
							Power Control Units	20	1	800-1000					25 lbs		36'	Yes	No	No	Yes	Yes	

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

SP 01T73

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SSD-PC-65

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	DISTANCE FROM AFT AIRLOCK	TRANSLATION CANDIDATES: HAND HOLDS	HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
							IVA (continued)																
							Batteries	10	1	800-1000	<	<	>		25 lbs		36'	Yes	No	No	Yes	Yes	
							Cameras	20	1	800-1000					20/Item		36'	Yes	No	No	Yes	Yes	
							Sensors	10-15	1	700-900					20/Item		36'	Yes	No	No	Yes	Yes'	
							Thermal Control Components (Pumps, accumulators, etc.)	20-40	1	800-1100					1-5 lbs/item		36'	Yes	No	No	Yes	Yes	
							Close/Repair Bulkhead Door	5-20	1	750-1000					5-46 lbs		36'	Yes	No	No	Yes	Yes	
							Repair Deployment Boom	15-20	1	800-1000		<	=		25		36'	Yes	No	No	Yes	Yes	

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
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SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

SSD—PC—65

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	*I SUIT REQUIREMENTS REF A7LB: MOBILITY *II	DEXTERITY *III	VISIBILITY *IV	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	LSS CANDIDATES: UMBILICAL SYSTEM	SELF CONT SYSTEM
44	Astronomy (Sortie)						Instrumentation:															
							Narrow Field UV Telescope															
							Deploy/Release				=	<	>									
							•Release Platform Lock Mechanism	15	1	900-1100							55'	Yes	No	No	Yes	Yes
							•Repair/Replace Cable Drive System	25	1	1000-1200	<											
							•Repair Fixed Stops	10	1	750-1000	<											
							Repair/Replace				<	<	>									
							•Offset Star Tracker	20	1	1000-1200				General Repair Kit	22 lbs							
							•Roll Drive	20	1	1000-1200					30 lbs							
							•Light Shade Drive	20	1	900-1100					15 lbs							
							•Roll Tracker	20	1	900-1100					22 lbs							
							•Roll Integ. Gyros	20	1	900-1100					12 lbs							
							Remove/Replace				=	=	>									
							•Film Cassettes	10	1	900-1000					20 lbs							
							•Protective Lens Cap	5	1	750-850					2-5 lbs							

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
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SSD—PC—65

SHUTTLE EVA/IVA UNSCHEDULED TASK ANALYSIS

FLT NO	PAYLOAD(S)	SENSITIVITY TO CONTAMINATION	MISSION FUNCTIONS D	R	S	E	UNSCHEDULED TASKS	TASK ASSESSMENT: TIME TO PERFORM TASK	NO. OF MEN REQUIRED	METABOLIC RATE	SUIT REQUIREMENTS REF A7LB: MOBILITY	DEXTERITY	VISIBILITY	SUPPORT EQUIPMENT REQUIRED: DESCR	WT	VOL	TRANSLATION CANDIDATES: DISTANCE FROM AFT AIRLOCK	HAND HOLDS HAND RAILS	MANEUVERING UNITS	MANIPULATOR	UMBILICAL SYSTEM	LSS CANDIDATES: SELF CONT SYSTEM
							Clean Lens	5	1	700-800	=						55	Yes	No	No	Yes	Yes
							Realignment Calibration	10	1	600-800				TV Camera	30 lbs							
							IR Telescope				>	<	>									
							•Remove Protective Cover	5	1	750-850					5-10 lbs		45'	Yes	No	No	Yes	Yes
							•Repair Super-Insulation	25	1	800-1000	<			-								
							Large Area Spark Chamber				=	<	>									
							•Remove Protective Cover	5m	1	750-850					15 lbs		45'	Yes	No	No	Yes	Yes
							•Clean Proton Telescope Lens	5	1	700-800				Active Clean Device or Facimily								
							•Repair/Replace	35	1/2	1000-1400	<				3080	20 ft^3						
							Totally or if possible									2 ft^3						
							•High Z Detector															
							•Anticoincidence Shield															
							Photoheliograph				=	=	>									
							•Remove/Replace Film Cassettes	10	1	900-1000							30'	Yes	No	No	Yes	Yes
							Repair Boom-Sensor Retraction Mechanism	15	1	900-1100	<	<	>		5 lbs		30'	Yes	No	No	Yes	Yes

D – DEPLOYMENT OF SATELLITE KICK STAGES, SERVICING MODULE, SORTIE CANS AND/OR SPACE STATION MODULES
R – RETRIEVAL OF SATELLITES OR KICK STAGES
S – SERVICING OF SATELLITE AND/OR SPACE STATION MODULES
E – EXPERIMENT CONDUCTION THROUGH USE OF SORTIE CANS

SP 01T73

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

SECTION 3.0

SHUTTLE EVA/IVA TASK TRANSLATION AND SUIT MOBILITY REQUIREMENTS

EVA/IVA TASK TRANSLATION & SUIT MOBILITY REQUIREMENTS

DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS Linear/Angular					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/TORQUE **	REACH *** One Handed	RESTRAINTS
Revisit(s) HEAO, LST, LSO, LRO	Planned EVA									
	Repair/Replace							60-80/100		
	RCS Thruster Assembly	35	10-55	M/A/MP	Totally	Heavy	0-2 in/0-5°		0-4 ft.	Portable Dutch Shoes, Waist (Var. Flex)
	Antenna	57	25-40	MP/A	Totally	Medium	0-1 ft/0-30°		0-4 ft.	P. Dutch Shoes and/or Handhold
	Solar Array Panel	45-56	40-50	MP/A	Totally	Medium	0-1 ft/0-30°		0-4 ft.	P. Dutch Shoes
	Secondary Mirror Drive Motor	65	10	MP/M/A	Arms Depth	Medium	0-2 in/0-5°		0-4 ft.	P. Dutch Shoes, Waist
	Sensors (wide angle sun)	35	2	MP/A	Totally	Medium	0-1 ft/0-30°		0-4 ft.	P. Dutch Shoes
	Magnetometer	40	17	M/A/MP	Totally	Medium	0-2 in/0-5°		0-2 ft.	P. Dutch Shoes, Waist (Flex)
	Star Trackers	40-65	67/unit	M/A	Totally	Medium	0-2 in/0-5°		0-2 ft.	P. Dutch Shoes, Waist (Flex)
	Detectors (Optical Cont)	70		MP/M	Totally	Light	0-1 ft/0-30°		0-4 ft.***	Handhold and/or Dutch Shoes
	Align/Calibration	30-65		MP/M		Medium	0-2 in/0-5°		0-2 ft.	D. Shoes, Waist
	Inspection/Clean	30-65		MP/M/A		Medium	0-2 in/0-5°		0-2 ft.	P. Dutch Shoes, Waist
	Refuel Operation	30	30	M/MP/A	Totally	Light	0-1 ft/0-30°		0-4 ft.***	Handholds and/or Dutch Shoes
	Unscheduled EVA									
	Repair/Replace							70-90/100		
	Light Shield	75		MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.***	Handhold
	Light Shield Actuator	75		MP/M/A	Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Flex Waist
	Electromechanical Drive (Solar Array Orientation)	40-50	5	MP/M/A	Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Flex Waist
	Locking Adapter	0		MP/A	Arms Depth	Light	0-1 ft/0-30°		0-4 ft.***	Handhold

M MANUAL
A POWER ASSISTED
MP MANIPULATOR ASSISTED

** NOTE: (1) This assessment is based upon a suit with the Shuttle EVA Suit/ATLP Design Goal Capabilities (mobility/torque) being provided.
(2) The value given indicates the percent of suit capability required to accomplish the task as defined herein.

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EVA/IVA TASK TRANSLATION & SUIT MOBILITY REQUIREMENTS

DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Revisit(s) HEAO, LST, LSO, LRO (Continued)	Unscheduled EVA (Continued)							70-90/100		
	Deployable Pressure Domes and Protective Covers	75		MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Aperture Doors/Motors, Rotating Members	75	5-10	MP/M/A	Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. Flex Waist
	Electromagnetic Torque Bar (Restrain also)	20		MP/A/M	Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. Flex Waist
	Thermal Protective Cover (Stow also)	20		MP/A	Arms Depth	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Unscheduled IVA									
	Replace Instrumentation	36		Manual	Elbow Depth to Totally	Light-Medium	0-2 in/0-5°	80-100/100	0-2 ft.	P.D.S. Waist and/ or Handhold
	Photoheliograph		200-1100							
	Spectrograph/Spectroheliograph		1100							
	UV Spectroheliograph		80							
	Coronograph		132							
	EUV Spectroheliograph									
	X-Ray Spectroheliograph									
	Crystal Spectroheliograph									
	Flare Detector									
	High Energy X-Ray Collimator		6-30							
	Large Area and Solid State Detector									
	High Resolution Crystal Spectrometer									
	Proportional Counter Array		196							
	Low Energy X-Ray Detector		400							
	Super Conducting Magnet									
	IR Spectograph									
	Scintillation Counter Array		318							

M MANUAL
A POWER ASSISTED
MP MANIPULATOR ASSISTED

SP 01T73

EVA/IVA TASK TRANSLATION & SUIT MOBILITY REQUIREMENTS

SSD–PC–66

DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS DISTANCE FT	TRANSLATION REQUIREMENTS MASS LBS	TRANSLATION REQUIREMENTS METHOD	PERFORMANCE CHARACTERISTICS ACCESSIBILITY	PERFORMANCE CHARACTERISTICS FORCES	PERFORMANCE CHARACTERISTICS POSITIONING ACCURACY Linear-Angular	PERFORMANCE CHARACTERISTICS MOBILITY/ TORQUE	PERFORMANCE CHARACTERISTICS REACH	PERFORMANCE CHARACTERISTICS RESTRAINTS
	Unscheduled IVA Cont'd.	36		Manual				80-100/100		
	Photoelectric Radiometer				Elbow Depth to Totally	Light-Medium	0-2 in/0-5°		0-2 ft.	Waist (Flex) P.D.S. and/or Handhold
	Vector Magnetograph									
	Longitudinal Field Magneto-graph		66							
	Electronic Detection Devices		110							
	Calibrate/Align/Checkout of Instrumentation							90-100/100		
	Replenish Consumables		33-1000		Totally	Light	0-1ft/0-30°	60-80/100	0-4 ft.**	Handholds
	Repair/Replace				Arm to Elbow Depth	Light-Medium	0-2 in/0-5°	80-100/100	0-2 ft	P.D.S, Waist (Flex) and/or handholds
	Tape Recorders		5-40							
	Remote Acquisition Units		10/item							
	Power Control Unit		25/item							
	Batteries		25/item							
	Cameras		20/item							
	Sensors		1-5item							
	Thermal Control Comp. (pumps, accum., etc.)		5-46		Hand to Elbow Depth					
	Close/Repair Bulkhead Door				Hand to Totally	Light	0-1ft/0-30°	60-80/100	0-4 ft*	Handhold
	Repair Deployment Boom				Arm to Elbow Depth	Medium	0-2in/0 5°		0-2 ft.	P.D.S. and Waist (Flex)

M MANUAL
A POWER ASSISTED
MP MANIPULATOR ASSISTED

SP 01T73

EVA/IVA TASK TRANSLATION & SUIT MOBILITY REQUIREMENTS

DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS: DISTANCE FT	TRANSLATION REQUIREMENTS: MASS LBS	TRANSLATION REQUIREMENTS: METHOD	PERFORMANCE CHARACTERISTICS: ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
General Applications Research Module	Thermal Coating Refurbishment	60						80-100/100		
	Data Acquisition		8	MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Photograph Exposure Plates		10-15		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Refurbish Coating		5-10		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Leak Detection and Repair	40								
	Data Acquisition		3-10	MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Employ Repair Techniques		10		Hand to Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Maintainable Attitude Control Propulsion System	25								
	Connect/Disconnect Video/ Photographic Equipment		20-25	MP/M/A	Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Connect/Disconnect Power Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Close/Open Prop. Feed Valves				Hand Depth	Light	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Replace/Reinsert Assem. or Components		100		Elbow to Totally	Heavy	0-2 in/0-5°		0-2 ft.	(Rigid, variable flex)
	Ball Bearing Lubrication	60								
	Mount/Disassemble Test Assembly		25	MP/M/A	Hand to Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Connect/Disconnect Power and Instrumentation Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Seal Assembly in Protective Containers		5-10		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold

M MANUAL
A POWER ASSISTED
MP MANIPULATOR ASSISTED

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EVA/IVA TASK TRANSLATION & SUIT MOBILITY REQUIREMENTS

DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
General Applications Research Module	Space Exposure Effects on Material Bulk Properties	60						80-100/100		
	Mount/Disassemble Assembly		150	MP/M/A	Totally	Heavy	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist (Rigid ViFlex)
	Retrieve/Replace Samples		45		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist and/or hand
	Place in Airlock/Glove Chamber				Arms Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Seal in Protective Container		50		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Advanced Guidance Subsystem Eval.	25								
	Ingress/Egress Free Flyer			M	Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Install/Remove Exp.		50		Totally	Heavy	0-2 in/0-5°		0-2 ft.	P.D.S. Waist (Rigid, ViFlex)
	Checkout Equipment				Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or Handhold
	Connect/Disconnect Test Apparatus to Digital Data Acq. System		30		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Space Exposure Effects on Material Fatigue Properties	60								
	Mount/Disassemble Fatigue Specimen Fixture		2-5	MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or Handhold
	Retrieve Specimens		6		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or Handhold
	Place/Retrieve (from) in Airlock/ Glove Chamber				Arms Depth	Light	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Package Specimen in Vacuum Tight Cont.		20		Totally	Light	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
General Scientific Research Mod.	Surface Degradation Exper.	35		MP/M/A				80-100/100		
	Install/Disassemble exposure racks	↓	20	↓	Totally	Medium	0-2"/0-5°	↓	0-2 ft.	P.D.Shoes, Waist, and or hand
	Place/Retrieve exposure strips in racks	↓		↓	Hand Depth	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or handhold
	Install/Disassemble Quartz Crystal Contam. Gage	↓	2-5	↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or handhold
	Data Acquisition	↓	8	↓	Arm Depth to Totally	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or handhold
	Engage/Disengage Power Lines	↓		↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	Handhold
	Place Exposure Strips in Prot. Containers	↓	15	↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or handhold
	Backfill Containers (Argon)	↓		↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	Handhold
	Active Cleaning Tech. Eval.	70						↓		
	Data Acquisition	↓	8	M/A	Arm to Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	P.D.S. and/or handhold
	Perform Cleaning Operation	↓	5-10	↓	Arm to Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	P.D.S. and/or handhold
	Contamination Control Evaluation	35						↓		
	Mount/Disassemble Test Panel	↓	20	M /M/P/A	Totally	Medium	0-2"/0-5°	↓	0-2 ft.	P.D.S. Waist and/or handhold
	Engage/Disengage Power and Gas Lines	↓		↓	Hand to Totally	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or handhold
	Contaminant Dispersal Measur.	50-100						↓		
	Mount/Disassemble High Resolution Camera	↓	50	A/M	Totally	Medium	0-2 in/0-5°	↓	0-2 ft.	P.D.S., Waist
	Replace/Retrieval Film Cassettes	↓	4/Item	↓	Hand to Elbow	Light	0-1 ft/0-30°	↓	0-4 ft.	P.D.S., and/or handhold
	Engage/Disengage Lines	↓		↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	Handhold

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS: DISTANCE FT	TRANSLATION REQUIREMENTS: MASS LBS	TRANSLATION REQUIREMENTS: METHOD	PERFORMANCE CHARACTERISTICS: ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
General Scientific Research Mod. (cont'd)	Contaminant Cloud Compos. Meas.	50						80-100/100		
	Attach/Detach Mass Spec. Sensor Head		5	MP/A/M	Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Engage/Disengage Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Integrated Real-Time Contam. Monit.	25-30								
	Attach/Detach Package		22	MP/M/A	Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Engage/Disengage Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Retrieve Sample Trays				Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Place in Transit Cases		15-20		Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Real Time Contam. Measurements	30								
	Attach /Detach Cont. Gage		8	MP/M/A	Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Engage/Disengage Elect and instrumentation Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Place in Prot. Cont.		20		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Backfill Containers				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Sky Background Brightness Meas.	50								
	Deploy/Retrieve Polarmeter Assy.		25	MP/M/A	Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	Engage/Disengage Power Lines				Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold
	Attach/Detach Closure Shuttle Device				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Repair Deployment Device				Hand to Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or handhold

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH ** One Handed	RESTRAINTS ***
Astronomy (Sortie)	EVA									
	Narrow Field UV Telescope	55		M ↓				80-100/100 ↓		
	Repair/Replace									
	Deployment Mechanism									
	Release Platform Lock Mechanism		5		Hand Depth	Medium	0-1 ft/0-30°		0-4 ft.	D. Shoes and Hand-hold
	Cable Drive System		5-10		Elbow Depth	Medium	0-1 ft/0-30°		0-4 ft.	D. Shoes and Hand-hold
	Fixed Stops				Hand Depth	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	Offset Star Tracker		22		Totally	Medium	0-2 in/0-5°		0-2 ft.	Waist and Hand-hold
	Roll Drive		30		Hand Depth	Medium	0-2 in/0-5°		0-4 ft.	Waist and Hand-hold
	Light Shade Drive		15		Totally	Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Hand-hold
	Roll Tracker		22		Totally	Medium	0-2 in/0-5°		0-2 ft.	Waist and Hand-hold
	Roll Integrated Gyros		12		Totally	Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Remove/Replace			M ↓				90-100/100 ↓		
	Film Cassettes		20		Hand to Elbow Depth	Light	0-1 ft/0-30°		0-4 ft.	Handhold
	Protective Lens Cover		2-5		Totally	Light	0-1 ft/0-30°		0-4 ft.	Handhold
	Clean Lens		5-15	M	Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Realignment Calibration			M ↓						
	Screw Adjustments				Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Mount/Dismount Camera (TV)		30		Arm Depth	Medium	0-2 in/0-5°		0-2 ft.	Waist and Hand-hold

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH ** One Handed	RESTRAINTS ***
Astronomy (Sortie) (continued)	IR Telescope									
	Remove Protective Cover	30		M ↓	Totally	Light	0-1 ft/0-30°	80-100/100	0-4 ft.	D. Shoes or Handhold
	Repair Super Insulation		5-10	↓		Light	0-1 ft/0-30°		0-4 ft.	D. Shoes or Handhold
	Large Area Spark Chamber			M ↓						
	Remove Protective Cover	45				Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Clean Proton Telescope Lens		5-15			Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Repair/Replace									
	High Z Detector					Medium	0-2 in/0-5°		0-2 ft.	D. Shoes, and/or Waist and Handhold
	Anticoincidence Shield					Light	0-1 ft/0-30°		0-4 ft.	Waist and/or Handhold
	Repair Boom-Sensor Retraction Mechanism	30	5	↓		Light	0-1 ft/0-30°		0-4 ft.	D. Shoes and/or Handhold
	Deploy/Retract Sortie Can Radiator	30		MP/A		Light-Medium	0-1 ft/0-30°		0-4 ft.	D. Shoes and/or Handhold
	IVA									
	Calibration/Operate/Monitor Equipment	25		M		Light	0-1 ft/0-30°		0-4 ft.	D. Shoes

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH **One Handed	RESTRAINTS
Payload Deployment Manipulator (I)	A. Inspection of Malfunctioned Item	60		M/M P		Light	0-1 ft/0-30°	70-90/100	0-4 ft.**	Handhold
	Photograph		10	M/M P		Light	0-1 ft/0-30°		0-4 ft.	P. Dutch Shoes
	B. Payload Doors Failure to Open	60		M				60-80/100		
	•Release Latch Mechanism				Hand Depth	Med - Heavy	0-2 in/0-5°		0-2 ft.	P.D.S., Waist (Var. Flex)
	•Lubricate Mechanisms		5		Hand Depth	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	•Extract/Reinstall Rotating Mechanism or Drive Motor		5		Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S., Waist (Flex)
	•Remove Appendages		5			Light-Medium	0-1 ft/0-30°		0-4 ft.	Hand, and/or P.D.S.
	•Perform Manual Deployment		5		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist (Flex)
	•Connect Umbilicals for Defuel Sequence				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	C. Manipulator Tiedowns Fail to Release	60		M				70-90/100		
	•Repair Captive Latches				Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	•Operate Manual Override Provisions		5		Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	•Deburr and Lubricate		10			Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	•Checkout Force Feedback Sensors and Circuitry		10-15		Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	P.D. Shoes
	D. Video Camera Fails	60						80-100/100		
	•Verify Lens Cover Removed				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	•Electrical Continuity Check		10-15		Totally	Light	0-1 ft/0-30°		0-4 ft.	Handhold or P.D.S
	•Remove/Install Auxiliary Pay Load Bay Camera		20-25		Hand to Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS: DISTANCE FT	MASS LBS	METHOD	PERFORMANCE CHARACTERISTICS: ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Deployment Manipulator (I) (continued)	E. Payload Restraints Fail to Release (see C)			M						
	F. Manipulator Fails to Align With Payload Attachment Points	60						80-100/100		
	●Provide Supplemental Lighting		5-10			Light	0-1 ft/0-30°		0-4 ft.	Hand or P.D.S.
	●Readjust Video Orientation and Docking Aid				Totally	Light	0-1 ft/0-30°			Hand or P.D.S.
	●Assist for Proper Alignment					Light	0-1 ft/0-30°			Hand or P.D.S.
	●Provide Guidance Instrumentation									
	●Provide Boom Oscillation Damping Force					Light	0-1 ft/0-30°		0-4 ft.	Hand or P.D.S.
	G. Manipulator Fails to Engage With Payload Attachment Points	60						80-100/100		
	●Provide Suppl. Force					Light Medium	0-1 ft/0-30°		0-4 ft.	Hand and/or P.D.S.
	●Replace End Effectors				Totally	Light Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and/or Waist
	●Verify Attach. by Applic. of Force Equal in Magnitude to Translation Maneuvers					Light Medium	0-1 ft/0-30°		0-4 ft.	Hand and/or P.D.S.
	●Checkout Touch Sensor Feedback and Circuitry		10-15		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S.
	H. Manipulator Fails to Raise Payload	60		M/A				60-80/100		
	●Provide Supplemental Forces					Medium-Heavy	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	●Replace Drive Motor		5-10		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and/or Waist

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Deployment Manipulator (I) (continued)	I. Manipulator Inoperable	60		M/A				80-100/100		
	●Attach Deploy Mechanism	↓	200-300	↓	Totally	Light	0-1 ft/0-30°	↓	0-4 ft.**	Handhold
	●Remove Protective Covers				Elbow-Totally	Light	0-1 ft/0-30°		0-4 ft.	Hand or P.D.S.
	●Release Payload Tiedowns				Hand Depth	Medium-Heavy	0-2 in/0-5°		0-4 ft.	P.D.S. and Waist
	●Disconnect Service/Monitoring Umbilicals				Totally	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	●Extend Payload					Medium-Heavy	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	●Release Payload					Light	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	●Retract Mechanism					Light	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	J. Manipulator Fails to Disengage Payload	75		A/M				70-90/100		
	●Manually Release Payload	↓		↓	Hand Depth	Light-Medium	0-1 ft/0-30°	↓	0-4 ft.	P.D.S. and/or Handhold
	●Remove End Effector		5		Totally	Light-Medium	0-1 ft/0-30°		0-4 ft.	P.D.S. and/or Handhold
	K. Manipulator Fails to Retract Following Deployment	60		M/A				80-100/100		
	●Apply Suppl. Force	↓		↓		Light-Medium	0-1 ft/0-30°	↓	0-4 ft.	Handhold and/or P.D.S.
	●Apply Lubric. to Main Interface Joint		5		Hand Depth	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	●Replace Drive Motor		5-10		Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	●Checkout Circuitry		5-10		Totally	Light	0-1 ft/0-30°		0-4 ft.	P.D.S.
	L. Manipulator Fails to Align With Tiedowns	60		M				80-100/100		
	●Guide and Position	↓		↓		Light	0-1 ft/0-30°	↓	0-4 ft.	Hand or P.D.S.

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Deployment Manipulator (I) (Continued)	M. Tiedowns Fail to Secure ●See C ●Provide alternate means of restrain	60 ↓		M ↓				80-100/100 ↓		

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Deployment Pivot Mechanism (II)	A. Release Mech. Failure (Payload) See E	60		M				80-100/100		
	B. Pivot Mechanism Failure	30		M/MP				80-100/100		
	•Lubricate and Remove Appendages		10		Hand to Arms Depth	Light	0-1 ft/0-30°		0-4 ft.**	Handhold
	•Repair/Replace Electric Drive Motor		5-10		Hand to Arms Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	•Manually Crank to Vertical Position		5		Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	•Disconnect Payload From Pivot Mechanism and Attach to Manipulator to Exercise Task	60			Elbow to Totally	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	•Conduct Exp. in IV Mode									
	•Connect Support Umbilicals									
	C. Expandable Tunnel Unpressurizable	20		M				80-100/100		
	•Leak Detection		3-10		Hand Depth to Totally	Light	0-1 ft/0-30°		0-4 ft.	Hand or P.D.S.
	•Replace Faulty Valves				Arms Depth	Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and Waist
	•Repair Tunnel Structure				Hand Depth to Totally	Light-Medium	0-2 in/0-5°		0-2 ft.	P.D.S. and/or Waist
	•Accomplish Mission Objectives in IV Mode									

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Retrieval Direct Dock (I) (Service, Maintain and Return)	A. Inspection	60		MP/M/A				80-100/100		
	Photograph		10	MP/M/A						
	B. Docking Adapter anomaly							80-100/100		
	●Failure of Pivot Mechanism See Deployment IIB Direct Dock to Forward Section a consideration. Berthing Adapter may be required per ●Payload Design									
	Payload Bay Doors fail to Open (see Deploy. IB)									
	●Visual Aids Damaged/ Misaligned	50		MP/M/A						
	Replace/Realign									
	Provide Guidance Instr.									
	●Inability to Establish Hard Dock									
	Lubricate, Remove Append.	210	10	MP/M/A	Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	Dutch Shoes and/ or Handhold
	Repair Captive Latches				Hand Depth	Medium	0-2 in/0-5°		0-2 ft.	Dutch Shoes, Waist
	Checkout Sensor and Circuitry				Hand Depth	Light	0-1 ft/0-30°		0-4 ft.	D. Shoes
	Transfer of Equipment Conduct Service/Maint. as Required		Varies							
	Conduct Retrieval with Mechanisms (similar to deploy II)	60								

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		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Retrieval Manipulator Capture and Dock (II) (Service and Maintenance)	●Payload Doors Fail to Open See Deploy IB							80-100/100		
	●Manipulator Tiedowns Fail to Release See Deploy IC									
	●Video Camera Fails See Deploy ID									
	●Manipulator Fails to Engage Payload Attachment See Deploy IG									
	●Manipulator Fails to Align with Payload Attachment See Deploy IF									
	●Manipulator Fails to Align Payload with Adapter Manually Guide into proper orientation	50		MP/M/A		Light	0-1 ft/0-30°		0-4 ft.	Dutch Shoes
	●Docking System Anomaly See Direct Dock Retrieval IB									

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DISCIPLINE	TASK REQUIREMENTS	TRANSLATION REQUIREMENTS			PERFORMANCE CHARACTERISTICS					
		DISTANCE FT	MASS LBS	METHOD	ACCESSIBILITY	FORCES	POSITIONING ACCURACY	MOBILITY/ TORQUE	REACH	RESTRAINTS
Payload Retrieval (III) (Return to Earth)	Manipulator Inoperable Similar to Deploy II Inability to Align Payload with Restraints Similar to Deploy IL Payload Tiedowns Fail to Secure Similar to Deploy IC Manipulator Fails to Disengage Payload See Deploy IJ Manipulator Fails to Retract Subsequent to Retrieval See Deploy IK Manipulator Fails to Align With Tiedowns See Deploy IL Manipulator Tiedowns Fail to Engage Similar to Deploy IC							80-100/100		

M MANUAL
A POWER ASSISTED
MP MANIPULATOR ASSISTED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE

A large number of the Shuttle missions during the period extending from 1979 to 1990 (a total of 677 flights) can be utilized to either retrieve or service satellites which are presently operating in orbit, or have been deactivated, or become dormant. These operations could not only yield valuable scientific information as to the long term effects of the space environment on materials and components, but might provide an additional method of cost reduction by the extension of satellite life.

Tables A4-1 and A4-2 represent United States and foreign vehicles (respectively) presently in an orbit (up to launch date of 1-1-70) which the Shuttle can feasibly attain. Included in the list are classified payloads where potential retrieval is an important consideration due to the inherent nature of the vehicles function. Table A4-3 indicates some representative payloads and the associated Shuttle flights that can accommodate the retrieval/service operation. It should be noted that the implementation of the tug into the Shuttle program provides added flexibility in attaining the goals of satellite retrieval/service.

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE INT'L. DESIGNAT.	PROJECT DIRECT	SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA INCLIN.	APOGEE	PERIGEE	STATUS (All In Orbit) As of 1-1-70
Tiros 1	4-1-60	1960 B2	NASA	265	48.3	468	430	Met. Photos until (6-17-60)
Midas 2	5-24-60	1960 Z1	USAF	5000	33.0	321	299	Data link quit 2nd day
Transit 2A	6-22-60	1960 H1	USN	223	66.7	665	389	Nav., Geodetic data (8-62)
Solrad 1	6-22-60	1960 H2	USN	42	66.8	657	382	Solar data (4-61)
Tiros 2	11-23-60	1960 II1	NASA	278	48.5	452	387	Cloud cover photos (12-4-61)
Samos 2	1-31-61	1961 A1	USAF	4100	97.0	350	300	Micromet. impact data
Transit 4A	6-29-61	1961 01	USN	175	67.0	623	534	Nuclear power supply
Injuni/Solrad 3	6-29-61	1961 02	USN	55/40	67.0	634	534	No separation; inj rad. data (3-63), Sol Xray (late 61)
Tiros 3	4-12-61	1961 P1	NASA	285	47.8	506	461	Photos (2-27-62)
Transit 4B	11-15-61	1961 AH1	USN	190	32.4	700	582	(7-62)
Traac	11-15-61	1961 AH2	USN	240	32.4	720	562	Grav. grad. exp. boom failed to deploy
Tiros 4	2-8-62	1962 B1	NASA	287	48.3	525	441	Cloud cover photos(6-10-62)
Oso 1	3-7-62	1962 Z1	NASA	458	32.8	370	344	Data on Solar flares (8-6-63)
Ariel 1	4-26-62	1962 01	NASA/UK	132	53.9	754	242	Ionospheric, X-Ray, Cosmic Ray Data (11-64)
Tiros 5	6-19-62	1962 AA1	NASA	286	58.1	604	367	Cloud cover photos (5-4-63)
None	8-23-62	1962 A01	USAF	-	98.6	526	388	Classified payload
Tiros 6	9-18-62	1962 AΨ1	NASA	281	58.2	444	423	Cloud cover photos (10-11-63)
Anna 1B	10-31-62	1962 BM1	USN	350	50.1	728	670	Geodetic data

* Vehicles considered are within a distance of 1000 nm of earth

TABLE A4–1. POTENTIALLY RECOVERABLE SPACE VEHICLES – UNITED STATES

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE: INT'L. DEISGNAT.	NOMENCLATURE: PROJECT DIRECT	SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA: INCLIN.	INITIAL ORBITAL DATA: APOGEE	INITIAL ORBITAL DATA: PERIGEE	STATUS (All in Orbit) As of 1-1-70
Explorer 16	12-16-62	1962 BX1	NASA	222	52.0	733	466	Micromet. data (7-22-63)
Transit 5A	12-18-62	1962 BV1	USN	135	90.7	455	432	Power failure first day
None	2-19-63	1963 5A	USAF	-	100.5	496	304	Classified payload
Tiros 7	6-19-63	1963 24A	NASA	297	58.2	401	385	Photos (2-3-66)
Geophysical Res.	6-28-63	1963 26A	USAF	220	49.8	808	267	Space gas exp. (13 orbits)
None	9-28-63	1963 38B	USAF/USN	160	89.9	714	676	Classified payload
None	9-28-63	1963 38C	"	120	89.9	705	667	Radiation Sat.
None	12-5-63	1963 49B	"	-	90.0	690	665	Classified payload
None	12-5-63	1963 49C	"	-	90.0	689	666	Classified payload
Tiros 8	12-21-63	1963 54A	NASA	265	58.5	474	430	Deactiv. (7-1-67)
None		1964 1A		-	69.9	582	563	Classified payload
GGSE 1		1964 1B		-	70.0	585	560	Grav. Grad exp.
Secor 1	1-11-64	1964 1C	USN/USAF	40	69.9	582	563	Deactiv.
Solrad 7A		1964 1D		100	69.9	582	563	Solar Rad (7-66)
None		1964 1E		-	69.9	591	555	Classified payload
None	1-19-64	1964 2B	USAF	-	99.0	518	500	Classified payload
None		1964 2C	USAF	-	99.1	514	501	Classified payload
None	6-3-64	1964 26A	USN	-	90.4	594	531	Classified payload
None	6-17-64	1964 31A	USAF	-	99.8	523	514	Classified payload
None		1964 31B	USAF	-	99.8	523	515	Classified payload

TABLE A4–1. CONTINUED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INT'L DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
Explorer 20	8-25-64	1964 51A	NASA	97	79.9	634	541	Ionospheric data (7-66)
Nimbus 1	8-28-64	1964 52A	NASA	830	98.6	579	263	Cloud Cover photos (9-23-64)
None	10-6-64	1964 63B	USAF/USN	-	89.9	673	657	Classified payload
None		1964 63C	"	-	89.9	674	655	Classified payload
None		1964 63E	"	-	90.0	673	657	Classified payload
Explorer 22	10-9-64	1964 64A	NASA	116	79.7	669	549	Ionospheric and geodetic data
Explorer 23	11-6-64	1964 74A	NASA	295	51.9	609	288	122 micrometeroids 1st yr.7-66
None	12-12-64	1964 83C	USAF/USN	172	90.0	672	639	Retur. Mag. field.
None		1964 83D	"	-	90.0	672	639	Classified payload
None	1-18-65	1965 3A	USAF	-	98.8	511	293	Classified payload
OSO 2	2-3-65	1965 7A	NASA	545	32.9	393	343	Solar X-Ray, gamma ray (11- 5)
Pegasus 1	2-16-65	1965 9A	NASA	23,000	31.7	462	308	Micrometeroid sat., 2300 sq ft of sensors; silenced 8-68
None	3-9-65	1965 16A		-	70.1	584	564	Classified payload
GGSE 2		1965 16B		-	70.1	583	562	Grav. grad. stab. exp.
GGSE 3		1965 16C		-	70.1	583	562	" " " "
Solrad 7B		1965 16D	USN/	-	70.1	583	562	Solar radiation satellite
Secor 3		1965 16E	USA/	40	70.1	583	562	Geodetic satellite; deact.
Oscar 3		1965 16F	USAF	33	70.1	585	565	3rd amateur "ham" radio sat.
Surcal		1965 16G		-	70.1	585	564	Surveillance calib. sat.
Surcal		1965 16H		-	70.1	586	563	Dodecahedron surveillace calib. satellite.

TABLE A4-1. CONTINUED

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INT'L. DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
None	3-17-65	1965 21A	USAF	-	99.1	475	326	Classified payload
Snapshot		1965 27A		-	90.2	826	805	In orbit: power supply oper. for 43 days
Secor 4	4-3-65	1965 27B	USAF/	40	90.2	816	797	Geodetic sat., failed to oper. as planned
None		1965 27E	USA	-	90.2	817	795	Classified payload
Explorer 27	4-29-65	1965 32A	NASA	132	41.2	819	584	Geodetic & ionospheric res. satellite
None	5-20-65	1965 38A	USAF	-	98.7	592	352	Classified payload
Pegasus 2	5-25-65	1965 39A	NASA	23,100	31.7	466	314	Meteroid detection sat.
None	6-24-65	1965 48A	USN	135	90.0	705	642	In orbit: active, augments operational navsat system
Tiros 10	7-2-65	1965 51A	NASA	280	98.6	517	458	In orbit: ab ndoned 7-3-67
Surcal		1965 65B		-	90.0	738	680	Surveillance calibration sat., failed to sep. from 2nd stage failed to deploy 200ft antenna
Surcal	8-13-65	1965 65C	USN	-	90.0	738	680	Dodacahedron, ext. 12-25' ante.
Surcal	8-13-65	1965 65E	USN	-	90.0	738	680	Tempsat, 14" sphere painted dull black
None	8-13-65	1965 65F	USN	135	90.0	738	680	Nav. Sat. -USN system
Surcal	8-13-65	1965 65H	USN	-	90.0	738	680	14" white sphere to check Spasur system
Surcal	8-13-65	1965 65L	USN	-	90.0	738	680	Rectangular package with beacon transmitter.
None	9-9-65	1965 72A	USAF	-	98.7	657	401	Classified payload
OGO 2	10-14-65	1965 81A	NASA	1118	87.4	941	260	Geophyscial sat. deact. 2-68

TABLE A4–1. CONTINUED

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION UA®

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INT'L. DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
OV2 1/L CS2	10-15-65	1965 82A	USAF	375/75	32.6	492	439	Transtage broke, failed to release payloads
None	1-28-66	1966 5A	USN	-	89.7	755	536	Active classified payload
ESSA 1	2-3-66	1966 8A	ESSA	305	97.9	521	432	1st oper. ESSA metsat switched off 5-8-67
ESSA 2	2-28-66	1966 16A	ESSA	290	101.0	885	843	In orbit: completed initial ESSA global system, APT cameras; still operational
OVI 4	3-30-66	1966 25A	USAF	193	144.5	630	550	In orbit: returned zero-g, thermal control exp. data
OVI 5	3-30-66	1966 25B	USAF	252	144.7	659	613	In orbit: optical radiation test, gravity-gradient stabli.
None	3-30-66	1966 26A	USAF	-	98.6	581	394	In orbit: classified payload
OAO 1	4-8-66	1966 31A	NASA	3917	35.[illegible]	500	492	In orbit: battery failed second day in orbit
None	5-14-66	1966 39B	USAF	-	109.9	345	323	In orbit: classified payload
Nimbus 2	5-15-66	1966 40A	NASA	912	100.3	734	684	In orbit: returned TV, IR cloud cover photos; silenced 1-18-69
None	5-19-66	1966 41A	USN	-	90.0	610	535	In orbit: classified payload tx on 150 mHz, 400 mHz
OVI 8	7-13-66	1966 63A	USAF	23	144.2	635	612	In orbit: 30' wire mesh sphere for passive comsat tests
None	8-16-66	1966 74B	USAF	-	93.2	324	318	In orbit: classified payload
None	8-17-66	1966 76A	USN	-	88.9	687	654	In orbit: classified payload tx on 150 mHz, 400 mHz
None	9-15-66	1966 82A	USAF	-	98.5	560	433	In orbit: classified payload, initial use of Burner II.

TABLE A4–1. CONTINUED

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE INT'L. DESIGNAT.	PROJECT DIRECT	SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA INCLIN.	APOGEE	PERIGEE	STATUS (All in Orbit) As of 1-1-70
ESSA 3	10-2-66	1966 87A	ESSA	320	101.0	923	860	In orbit: replaced ESSA 1 in TOS system, silecned 10-9-68
OVI 10	12-11-66	1966 111B	USAF	287	93.5	479	403	In orbit: gravity-stablized radiation sat., both deactive
ESSA 4	1-26-67	1967 6A	ESSA	290	102.0	894	822	In orbit: replaced ESSA 2, camera failure caused deactive 12-6-67
None	2-8-67	1967 10A	USAF	-	98.8	544	489	In orbit: classified payload
OSO 3	3-8-67	1967 20A	NASA	627	32.9	354	336	In orbit: solar observatory, nine exp. returing data
None	4-13-67	1967 34A	USN	-	90.3	672	652	In orbit: classified payload
ESSA 5	4-20-67	1967 36A	ESSA	320	101.9	883	840	In orbit: replaced ESSA 3, two AVCS cameras operational; now on standby
None	5-9-67	1967 43B	USAF	-	85.0	500	345	In orbit: classified payload
None	5-18-67	1967 48A	USN	-	89.6	685	667	In orbit: classified payload
Surcal		1967 53B		-	70.0	582	570	In orbit: 20" surveillance calibration sphere
GGSE 4		1967 53C		-	70.0	577	569	In orbit: gravity gradient stablization exp. satellite
GGSE 5		1967 53D		-	70.0	575	570	In orbit: gravity gradient stablization exp. satellite
None	5-31-67	1967 53E	USAF/USN	-	69.9	572	569	In orbit: classified payload
Surcal		1967 53F		84	69.9	575	569	In orbit: nav. exp. sat.
None		1967 53G		-	69.9	575	574	In orbit: classified payload
None		1967 53H		-	69.9	575	573	In orbit: classified payload
Surcal		1967 53J		-	70.0	577	569	In orbit: 16" surveillance calibration spere
OVI 86	7-27-67	1967 72A	USAF	231	101.6	431	346	In orbit: four experiments including cosmic ray telesc.
OVI 12	7-27-67	1967 72D	USAF	310	101.7	428	309	In orbit: flare activated radiological observatory
OGO 4	7-28-67	1967 73A	NASA	1216	86.0	564	256	In orbit: tape recorder failed 1-19-69

TABLE A4–1. CONTINUED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INT'L. DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
None	8-22-67	1967 80A	USAF	-	99.0	557	516	In orbit: classified payload
None	9-25-67	1967 92A	USAF/USN	-	89.3	693	647	In orbit: classified payload
None	10-11-67	1967 96A	USAF	-	99.2	536	415	In orbit: classified payload
OSO 4	10-18-67	1967 100A	NASA	597	32.9	354	334	In orbit: returned 1st pictures of sun in extreme ultraviolet
ESSA 6	11-10-67	1967 114A	ESSA	290	102.1	925	876	In orbit: returned photos of cloud cover every 6 min: deactivated 11-4-69 due to degraded vidicon and excession drift out of sun synch
Explorer 36	1-11-68	1968 3A	NASA	460	105.8	976	671	In orbit: GEOS 2 returning geodetic data
None	1-17-68	1968 4A	USAF	-	75.1	335	284	In orbit: classified payload
None	1-24-68	1968 8B	USAF	-	81.6	338	291	In orbit: classified payload
None	3-1-68	1968 12A	USAF	-	89.9	711	640	In orbit: classified payload
Explorer 37	3-5-68	1968 17A	USN/NASA	198	59.4	545	324	In orbit: Solar Explorer B returned radiation data despite off-nominal orbit
None	3-14-68	1968 20B	USAF	-	83.1	326	299	In orbit: classified payload
None	5-22-68	1968 42A	USAF	-	98.9	560	509	In orbit: classified payload
None	6-20-68	1968 52B	USAF	-	85.1	321	272	In orbit: classified payload
ESSA 7	8-16-68	1968 69A	ESSA	320	101.7	913	889	In orbit: replaced Essa 5 as primary stored data satellite in TOS System; one camera returned cloud cover photos; recorders failed; deactiv.7-19-69
None	10-5-68	1968 86A	USAF	-	75.0	316	301	In orbit: classified payload
None	10-22-68	1968 92A	USAF	-	99.0	529	497	In orbit: classified payload

TABLE A4–1. CONTINUED

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INITIAL DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
TETR 2	11-8-68	1968 100B	NASA	40	32.8	587	232	In orbit: 2nd orbiting target for NASA's Manned Space Flight
OAO 2	12-7-68	1968 110A	NASA	4446	34.99	485	479	In orbit: 11 telescopes studying stars in UV, IR, gamma & X-rays.
None	12-12-68	1968 112B	USAF	-	80.3	916	862	In orbit: classified payload
ESSA 8	12-15-68	1968 114A	ESSA	290	101.8	910	880	In orbit: 2 APT cameras sending cloud cover photos every 6 min.
OSO 5	1-22-69	1969 6A	NASA	641	32.9	349	333	In orbit: returning data on solar radiation
None	2-5-69	1969 10B	USAF	-	80.4	895	866	In orbit: classified payload
ESSA 9	2-26-69	1969 16A	ESSA	320	102	943	883	In orbit: final ESSA launch in TOS System, replaced ESSA 7; fully operational, carries AVCS
OVI 17	3-17-69	1969 25A	USAF	312	99.1	291	247	In orbit: 12 experiments measuring solar radiation
OVI 18	3-17-69	1969 25B	USAF	275	98.8	362	289	In orbit: studying ionosphere; measuring radio interference electric fields radiation
None	3-19-69	1969 26B	USAF	-	83	319	313	In orbit: classified payload
Nimbus 3	4-14-69	1969 37A	NASA	1269	99.9	703	665	In orbit: 3rd metsat returning IR, UV, geodetic, and TV data
Secor 13	4-14-69	1969 37B	USA	45	99.9	703	665	In orbit: army geodetic sat; deactivated
None	5-1-69	1969 41B	USAF	-	65.7	293	253	In orbit: classified payload
OGO 6	6-5-69	1969 51A	NASA	1393	81.9	683	248	In orbit: geophysical observ. completing launch program; 23 of 25 expmnts. returing data; celestial lyman-alpha expmnt. returned data until 6-23-69
None	7-22-69	1969 62A	USAF	-	98.8	533	488	In orbit: classified payload
None	7-31-69	1969 65A	USAF	-	75.0	333	289	In orbit: classified payload

TABLE A4–1. CONTINUED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) AS OF 1-1-70
		INITIAL DESIGNAT.	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
OSO 6	8-9-69	1969 68A	NASA	640	32.9	344	305	In orbit: advanced solar physics research platform; main new ability is offset raster scan near edge of sun's disk
PAC 1	9-9-69	1969 68B	NASA	265	32.9	343	302	In orbit: test of semi-active gravity-gradient stablization (SAGS) technique
None	9-22-69	1969 79B	USAF	-	85.1	308	305	In orbit: classified payload
None	9-30-69	1969 82A	USAF	-	69.6	303	299	In orbit: classified payload
None	9-30-69	1969 82B	USAF	-	70.7	586	575	In orbit: classified payload; launch probably included more satellites.
None	12-4-69	1969 105A	USAF	-	81.5	150	103	In orbit: classified payload

TABLE A4–1. CONTINUED

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE INT'L. DESIGN	NOMENCLATURE PROJECT DIRECT	SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA INCLIN.	INITIAL ORBITAL DATA APOGEE	INITIAL ORBITAL DATA PERIGEE	STATUS (All in Orbit) As of 1-1-70
Alouette 1	9-28-62	1962 BA1	CANADA	320	80.5	638	620	In orbit: 1st Canadian sat., continues to tx ionospheric data
Polyot 1	11-1-63	1963 43A	USSR	-	58.9	893	213	In orbit: first spacecraft with extensive maneuver cap.
Kosmos 44	8-28-64	1964 53A	USSR	-	65	534	384	In orbit: unannounced payload probable metsat
Kosmos 58	2-26-65	1965 14A	USSR	-	65	409	361	In orbit: unannounced payload probable metsat
Kosmos 71		1965 53A		-	56.1	342	342	In orbit: unannounced payload 1st Soviet 5-sat. payload laun.
Kosmos 72		1965 53B		-	56.1	342	342	In orbit: unannounced payload
Kosmos 73	7-16-65	1965 53C	USSR	-	56.1	342	342	In orbit: unannounced payload
Kosmos 74		1965 53D		-	56.1	342	342	In orbit: unannounced payload
Kosmos 75		1965 53E		-	56.1	342	342	In orbit: unannounced payload
Kosmos 80		1965 70A		-	56	932	932	In orbit: unannounced payload, 2nd Kosmos 5-payload launch
Kosmos 81		1965 70B		-	56	932	932	In orbit: unannounced payload
Kosmos 82	9-3-65	1965 70C	USSR	-	56	932	932	In orbit: unannounced payload
Kosmos 83		1965 70D		-	56	932	932	In orbit: unannounced payload
Kosmos 84		1965 70E		-	56	932	932	In orbit: unannounced payload
FR 1	12-6-65	1965 101A	France	132	75.9	484	458	In orbit: VLF wave propagation research satellite; inactive
Kosmos 103	12-28-65	1965 112A	USSR	-	56	373	373	In orbit: unannounced payload, 52nd Kosmos orbited in 1965

* Vehicles considered are within a distance of 1000 nm of earth

TABLE A4—2. POTENTIALLY RECOVERABLE SPACE VEHICLES — FOREIGN

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE INT'L. DESIGN	NOMENCLATURE PROJECT DIRECT	SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA INCLIN.	INITIAL ORBITAL DATA APOGEE	INITIAL ORBITAL DATA PERIGEE	STATUS (All in Orbit) As of 1-1-70
Kosmos 118	5-11-66	1966 38A	USSR	-	65	398	398	In orbit: unannounced payload, probable metsat
Kosmos 122	6-25-66	1966 57A	USSR	-	65	388	388	In orbit: metsat, launch witnessed by Gen.De Gaulle
D 1C	2-8-67	1967 11A	France	50	40.0	833	360	In orbit: geodetic satellite operational in spite of low apogee
Kosmos 144	2-28-67	1967 18A	USSR	-	81.2	388	388	In orbit: meterological sat. similar to Kosmos 122
Kosmos 151	3-24-67	1967 27A	USSR	-	56	391	391	In orbit: unannounced pay-load
Kosmos 156	4-27-67	1967 39A	USSR	-	81.2	391	391	In orbit: metsat, forms operational system with Kosmos 144
Ariel 3	5-5-67	1967 42A	UK	198	80.2	373	306	In orbit: first all-British research satellite
Kosmos 158	5-15-67	1967 45A	USSR	-	74.0	528	528	In orbit: unannounced payload
Kosmos 184	10-25-67	1967 102A	USSR	-	81.2	395	395	In orbit: 4th Soviet weather satellite
Kosmos 192	11-23-67	1967 116A	USSR	-	74	472	472	In orbit: unannounced payload
Kosmos 198	12-28-67	1967 127A	USSR	-	65.1	175	165	In orbit: maneuvered unannounced payload
Kosmos 200	1-20-68	1968 6A	USSR	-	74	333	333	In orbit: unannounced payload
Kosmos 203	2-20-68	1968 11A	USSR	-	74.08	746	746	In orbit: unannounced payload
Kosmos 206	3-14-68	1968 19A	USSR	-	81	391	391	In orbit: metsat; returing weather & infrared photos, thermal data

TABLE A4–2. CONTINUED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Orbit) As of 1-1-70
		INT'L. DESIGN	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
Kosmos 209	3-22-68	1968 23A	USSR	-	65.1	175	155	In orbit: unannounced payload; maneuvered to 556/590 mile orb.
Kosmos 220	5-7-68	1968 40A	USSR	-	74	472	416	In orbit: unannounced payload
Iris (ESRO 2B)	5-17-68	1968 41A	ESRO	164	97.2	677	205	In orbit: returning solar and cosmic radiation data
Kosmos 226	6-12-68	1968 49A	USSR	-	81.2	404	375	In orbit: 13th metsat; returning cloud cover photos & weather data
Kosmos 236	8-27-68	1968 70A	USSR	-	56	407	373	In orbit: unannounced payload; probable navsat
Aurorae (ESRO 1A)	10-3-68	1968 84A	ESRO	185	93.7	949	161	In orbit: investigating auroral pnenomena & polar ionosphere
Kosmos 248	10-19-68	1968 90A	USSR	-	62.3	342	304	In orbit: unannounced payload; maneuverable
Kosmos 250	10-31-68	1968 95A	USSR	-	74	345	325	In orbit: unannounced payload; possible navsat
Kosmos 256	11-30-68	1968 106A	USSR	-	74.06	767	726	In orbit: unannounced payload
Kosmos 269	3-5-69	1969 21A	USSR	-	74	347	327	In orbit: unannounced payload; possible navsat
Kosmos 272	3-17-69	1969 24A	USSR	-	74	758	743	In orbit: unannounced payload; possible navsat
Meteor 1	3-26-69	1969 29A	USSR	-	81.2	443	400	In orbit: metsat, returning cloud, snow, ice cover data during daylight & dark
Kosmos 275	3-28-69	1969 31A	USSR	-	71	500	176	In orbit: unannounced payload possible solar flare monitor

TABLE A4—2. CONTINUED

4.0 RETRIEVAL/SERVICING OF PREVIOUSLY LAUNCHED SATELLITE (CONTINUED)

SATELLITE NAME	LAUNCH DATE	NOMENCLATURE		SATELLITE WEIGHT (LBS)	INITIAL ORBITAL DATA			STATUS (All in Oribt) As of 1-1-70
		INT'L. DESIGN	PROJECT DIRECT		INCLIN.	APOGEE	PERIGEE	
Kosmos 292	8-14-69	1969 70A	USSR	-	74	488	464	In orbit: unannounced payload
Meteor 2	10-6-69	1969 84A	USSR	-	81.2	429	392	In orbit: metsat to expand weather service; monitors cloud and ice over, IR, and thermal energy reflected and radiated from Earth's atmos.
Intercosmos 1	10-14-69	1969 88A	USSR	-	48.4	398	162	In orbit: int'l. expmnts. from 3 E. European countries to study sun's UV, X-ray effects on upper atmosphere
Kosmos 303	10-18-69	1969 90A	USSR	-	71.0	306	175	In orbit: unannounced payload
Kosmos 304	10-21-69	1969 91A	USSR	-	74.0	481	464	In orbit: unannounced payload; possible nav/geodetic sat.
Kosmos 308	11-4-69	1969 96A	USSR	-	71.0	262	175	In orbit: unannounced payload
Kosmos 311	11-24-69	1969 102A	USSR	-	71.0	308	166	In orbit: unannounced payload
Kosmos 314	12-11-69	1969 106A	USSR	-	71.0	305	175	In orbit: unannounced payload
Kosmos 315	12-20-69	1969 107A	USSR	-	74.1	346	324	In orbit: unannounced payload; possible nav/geodetic sat.
Kosmos 317	12-23-69	1969 109A	USSR	-	65.4	1888	130	In orbit: unannounced payload
Intercosmos 2	12-25-69	1969 110A	USSR	-	48.4	685	128	In orbit: second int'l. sat. carrying E. European-made ionospheric observ. & survey experiments.

TABLE A4-2. CONTINUED

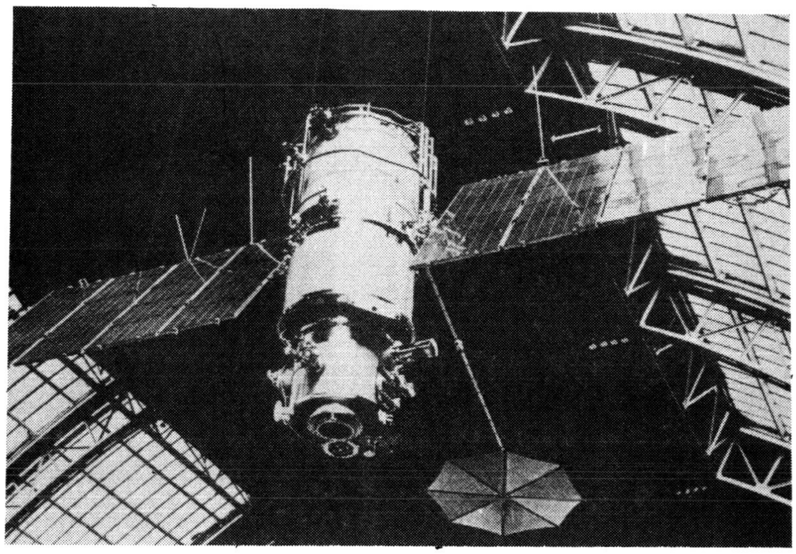
GENERAL PAYLOAD CLASSIFICATION	SHUTTLE FLIGHT DATA: FLIGHT NO.	SHUTTLE FLIGHT DATA: YEAR	SHUTTLE ORBIT CHARAC.: I	SHUTTLE ORBIT CHARAC.: HA	SHUTTLE ORBIT CHARAC.: HP	TYPICAL VEHICLES TO BE RETRIEVED OR SERVICED*	INITIAL VEHICLE ORBIT CHARACTERISTICS: I	INITIAL VEHICLE ORBIT CHARACTERISTICS: HA	INITIAL VEHICLE ORBIT CHARACTERISTICS: HP	PARAMETRIC DATA: WEIGHT (LBS)	PARAMETRIC DATA: ENVEL. (FT)	REMARKS
SATELLITE DE-PLOYMENT	2	1979	28.5	270	270	INTERCOSMOS 1 (USSR)	48.4	211	126	-	-	SEE REF. SHEET 1
SORTIE CAN & SAT. REVISIT	4-5	1980	28.5	200	200							
SATELLITE DE-PLOYMENT	2,5	1981	28.5	200-350	200-350	MIDAS 2	33.0	321	299	5000	-	
SORTIE CAN & REVISIT S.	6-7	1981	28.5	200	200							
SORTIE CAN DE-PLOYMENT & REVISIT	3	1982	28.5	200-270	200-270							
DEPLOYMENT & REVISIT	4	1982	28.5	200-350	200-350							
DEPLOYMENT & REVISIT	3,4	1983	28.5	270-350	270-350							
DEPLOYMENT	6	1983	28.5	350	350	OAO 2	34.99	485	479	4446	10'x7'D	SEE REF. SHEET 2 SOLAR PANELS RE-TRACTED
DEPLOYMENT & REVISIT	2	1984	28.5	200-270	200-270	OSO 3,4,5	32.9	349-354	333-336	579-641	3'x4'D	CAN ALSO BE ACCOMPLISHED ON THE MAJORITY OF THE REVISITS AND RE-TRIEVAL MISSIONS. SEE REF. SHEET 3
REVISIT	3,4,5	1984	28.5	200-350	200-350							
DEPLOYMENT & RETRIEVAL	3	1985	28.5	200-350	200-350							
REVISIT	4,5	1985	28.5	200-350	200-350							
DEPLOYMENT	6	1985	28.5	350	350	OV21/LCS2	32.6	492	439	375/75	3'x4.5'D	SEE REF. SHEET 4
DEPLOYMENT & REVISIT	7	1985	28.5	350	350						SOLAR PANELS RETRACT-ed	
DEPLOYMENT & REVISIT	2,3	1986	28.5	200-350	200-350							
REVISIT	4,5	1986	28.5	200-350	200-350							
DEPLOYMENT & REVISIT	2	1987	28.5	200-350	200-350							
DEPLOYMENT & RETRIEVAL	4	1987	28.5	200-350	200-350							
REVISIT	5,6,9	1987	28.5	200-350	200-350							
DEPLOYMENT	7	1987	28.5	350	350							
REVISIT	4,5,6	1988	28.5	200-350	200-350							
DEPLOYMENT & REVISIT	1,2 1,2	1989	28.5	200-350	200-350							
DEPLOYMENT & RETRIEVAL	5	1989	28.5	200-350	200-350							
REVISIT	6,7,9	1989	28.5	200-350	200-350							
RETRIEVAL	10	1989	28.5	350	350							
REVISIT	2,3,4,5	1990	28.5	200-350	200-350							
DEFLOYMENT	41	1985	28.5	200	200	NIMBUS 3	99.9	703	665	1269	10'x11'D MAX	OPERATIONAL TUG WILL BE AT 99-101° INCLINATION AND 500-700 NM ORBIT AND COULD POTENTIALLY RE-TRIEVE/SERVICE MANY PAYLOAD, INCLUDING CLASSIFIED VEHICLES. SEE REFERENCE SH SHEETS 5/6.
DEPLOYMENT	34,35,36	1986	28.5	200	200	CLASSIFIED PAYLOADS (US)	65.7	293	253			
DEPLOYMENT	41,42, 44,48	1987	28.5	200	200	CLASSIFIED PAYLOADS (US)	85.1	321	272			
DEPLOYMENT	33	1988	28.5	200	200	TIROS 8 (AND SERIES)	58.5	474	430	300	4',4'D	
DEPLOYMENT	42	1989	28.5	200	200						SOLAR PANELS RETRACTED	
DEPLOYMENT	35	1990	28.5	200	200	METEOR 2 (USSR)	82.2	429	392			

* ADDITIONAL OMS TANKAGE MAY BE REQUIRED FOR CERTAIN MISSIONS.

TABLE A4–3. POTENTIAL SHUTTLE UTILIZATION FOR SATELLITE RETRIEVAL/SERVICE

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

REFERENCE 1



METEOR AND INTERCOSMOS PROGRAMS

Up to this launch of Meteor 2, the USSR has launched what observers have presumed were 14 satellites for meteorological missions, including an early series of developmental versions which were announced as members of the all purpose Kosmos family. Some of these Kosmos metsats were shortlived and believed by observers to have been recovered; others, in a later phase of launchings, maintained stable orbits. These early possible metsats included some which the Soviet Union subsequently did announce as carrying meteorological payloads, and from which photographic data has been supplied to the U.S. under international agreement, by the World Meteorological Satellite Center in Moscow. The early Kosmos that observers presumed to have been metsat test missions included Kosmos 23, 44, 45, 65, and 92. Kosmos 122, launched in June 1966, was the first designated metsat containing television cameras; it could make dark-side measurements of the Earth through use of infrared sensor, and carried other radiation sensors.

Subsequent Kosmos announced as being metsats included 144, 156, 184, 206 and 226. The orbits of these five were phased so they provided virtually continuous coverage of the Earth's surface; their orbital periods varied only by 12 seconds. The first launch in the announced Meteor program occurred in March 1969.

Meteor Spacecraft Description

Details were not fully announced, but the Meteor satellite is presumed to be similar to the design for the previous Kosmos metsats; essentially a large cylindrical center body, incorporating meteorological instruments at the Earth-facing end. Electrical power is provided by solar cells which charge the storage batteries; solar cells are mounted on two large panels extending from the sides of the cylinder, and rotated to remain sun-oriented when the satellite is in sunlight; a drive mechanism fitted in the top end of the center body rotates the solar panels. A three-axis attitude control system which includes reaction wheels is used for satellite stabilization, to point the meteorological instruments to the Earth.

Retrieval:

Reaction of solar cells (repair retraction mechanism if required)
Remove Appendages

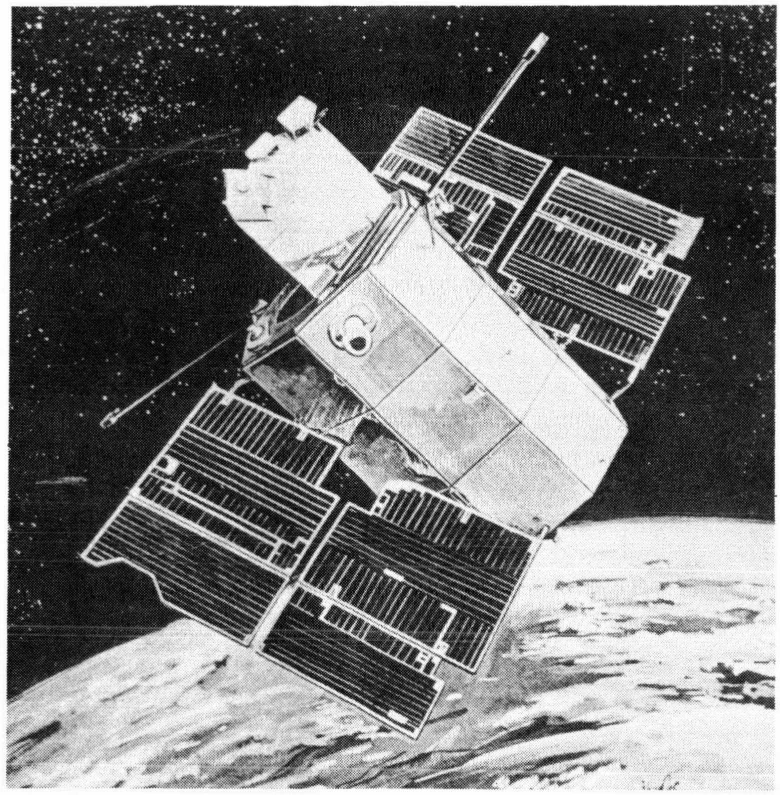
Intercosmos Spacecraft Description

Intercosmos 1: Details not widely published; however, photographs represent its general configuration as cylindrical, with hemispherical compartments at either end, folding solar arrays, and some externally mounted experiments.

Intercosmos 2: According to Soviet announcements, this satellite differs considerably from its immediate predecessor. Much of the previously externally mounted experiment packages are internally mounted on Intercosmos 2, in order to screen sensors; also, this satellite carries only a storage battery for electric power, having no solar arrays in order to avoid the generation of magnetic fields by the current flows in solar panels.

Retrieval: Remove Appendages

REFERENCE 2



ORBITING ASTRONOMICAL OBSERVATORY (OAO—2)

Although each OAO spacecraft differs in detail, in accordance with the requirements of the experiments each carries, they are all octogonal cylinders about 10 feet long and 6.7 feet across the flats, with an internal tube 40 inches in diameter for the experiment optics. The following paragraphs briefly summarize the construction of each major subsystem.

The spacecraft structure consists of the primary load-carrying structure, the outer non-load-carrying protective skin, and internal mounts for housing operating and experiment equipment in 48 bays mounted to hinged honeycomb panels which swing outboard for access to the equipment and wiring. The structure is designed to enable optical alignment of more than 30 items of spacecraft equipment to a common angular reference system.

The most important subsystem on the OAO is the stabilization and control subsystem. It uses gimbal star trackers as the basic attitude sensors. The OAO incorporates six trackers, two on each of the three control axes. Error signals, which are derived from a comparison of the commanded and the actual star-tracker gimbal angles while tracking a guide star, are processed into analog voltage to drive a fine inertial wheel on the appropriate control axes. The inertial wheels accelerate to rotate the spacecraft to the desired position by reaction.

A magnetic unloading system provides continuous momentum unloading of the inertial wheels. Saturation of the wheels is also prevented by the use of cold-gas jet actuators, which are set to fire when the wheels reach about 75 percent of their rated speed. Telemetry data indicate the magnetic unloading system on OAO-2 has been able to maintain inertial-wheel speeds within two to five percent, obviating the use of the jets.

The OAO design includes two stabilized pointing modes: a coarse pointing mode using star trackers, and a fine pointing mode. In the coarse pointing mode, the optical axis of an experiment is pointed with a circular error accuracy of one arc-minute RMS, and is designed with a drift of less than 15 arc-seconds over 50 minutes of time. The fine pointing mode was not required nor provided on OAO-2.

The OAO performs three orientation and stabilization maneuvers from the time of orbit injection until it reaches on-station attitude stabilization. Using simple rate gyros and fine and coarse solar sensors, the system initially reduces the rate about each axis and points the optical axis toward the sun. During re-orientation, slewing is achieved by the inertial wheels. A contingency rate and positioning sensing mode is used when the star trackers cannot maintain a coarse pointing mode, and orients the observatory with the sun normal to the plane of the solar cell array.

The solar-cell array, which when extended yields a total wingspread of 21 feet for OAO-2, supplies the power system load while the spacecraft is in sunlight, as well as recharging the three batteries on board. The nominal power system load is about 430 watts, which varies as the spacecraft moves from 65-percent-sunlit to 83-percent-sunlit orbits. The power demands for the experiments are duty-cycled, and are equivalent to 34 watts average.

The communications subsystem transfer commands to the spacecraft, command verification and status data from the spacecraft, and digital and analog real-time experiment data, via a wideband transmitter. A radio-tracking beacon transmits a continuous-wave signal.

Since ground control of the OAO is not continuous, data is transmitted both in a real-time and a delay mode. In real-time, commands are sent to the observatory (also for storage for later use) for controlling, programming, and performing experiments, as well as for sampling and preparing data both from the spacecraft's and the experiments' data-handling equipment.

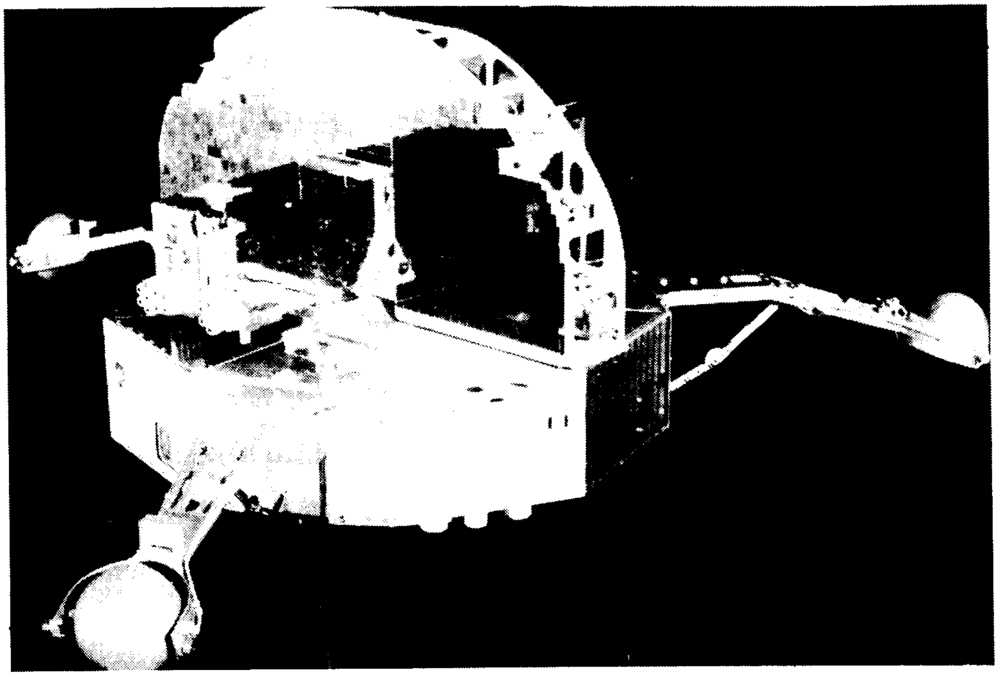
Thermal control on OAO is achieved both actively and passively. The heat from the electronic equipment, which is maintained between zero and 130°F, is insulated from the structure. and is mostly radiated to the skins and outer space. The structure can be designed to operate at an average stable temperature of either -22°F or +32°F. Temperature stability of the OAO-2 structure is maintained with ± 10°F, irrespective of the spacecraft pointing angle. The experiment packages are maintained within five degrees of the structure's temperature. Actively louvered heat sinks in some bays provide thermal control for certain items of equipment.

Retrieval/Maintenance

Retrieval:
- Remove appendages
- Retract solar cell array
- Repair mechanism (if required)

Maintenance:
- Repair Solar panels
- Remove protective skin
- Replace batteries
- Replace star tracker
- Refuel cold gas propellant
- Replace narrow band antenna
- Repair sunshade
- Replace earth sensor
- Replace instrumentation (experiment dependent)
- Remove protective lens cover

REFERENCE 3



ORBITING SOLAR OBSERVATORY (OSO 5)

Spacecraft Description

Same basic two-stage design as previous OSO's; overall height, 38 inches. Spinning wheel-like base, a nine-sided drum 44 inches in diameter, revolving at 30-40 rpm, allows five experiments housed in compartments in the base section to scan the sun every two seconds. Pitch-control system maintains the base spin axis perpendicular to the sun while overall spacecraft is pointed within one-minute-of-arc accuracy. Base also holds power, command, spin-control, and communication subsystems. Overall diameter increased to 92 inches with three spin-control booms (arms) are extended for stabilization, nitrogen gas stored in spheres at end of booms are part of controls for spin rate. Upper "sail" portion, fan shaped and 23 inches high, contains directionalized instrumentation and solar cell panels, faces the sun during daytime. Magnetic bias coil augments pitch control, saves gas consumption. Design lifetime, six months. Weight 641 pounds.

Spacecraft Description (Continued)

Retrieval/Maintenance

Retrieval:
- Retract spin control boom
- Repair boom retraction mechanism (if required)
- Remove appendages

Maintenance:
- Repair/replace solar panels
- Replace directional instrumentation
- Replace/refuel propellant (nitrogen)
- Replace AC engines
- Replace magnetic bias coils
- Replace batteries
- Repair/replace communications instrumentation (remove protective panel structure of nine sided base)

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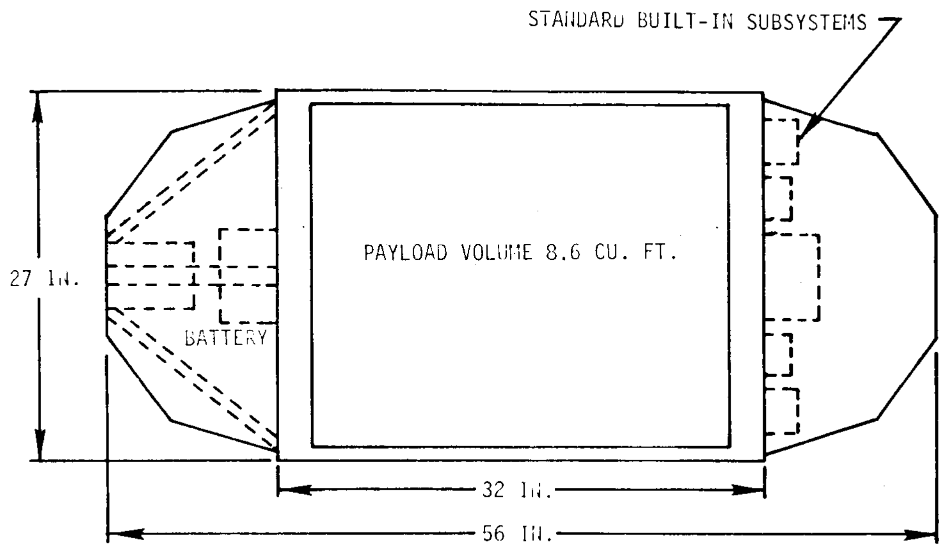
REFERENCE 4



ORBITAL VEHICLE ONE (OV1)

The multi-faceted domes at either end of the vehicle form the substructure for solar cells and enclose the subsystems. Together, the solar cells on the hemispherical domes form a spheroidal, nondirectional solar array. Electronics mounted on the forward bulkhead beneath the solar dome include telemetry, data storage, command control, and electrical power conditioning equipment. The satellite battery is housed under the aft dome.

Including all subsystems, the basic satellite weighs about 110 pounds; it is 27 inches in diameter, 56 inches long, and will accommodate up to 220 pounds of experiment equipment within the 8.6 cubic foot volume of the standard center section. The experiment volume has been varied for special missions by changing the length of the cylindrical center section. In this fashion, satellite weight and orbital performance can be optimized for a given experiment package at minimum modification cost. Center skins of the experiment section are bolted on to permit access to individual experiment packages.

Because the satellite structure is almost entirely aluminum, the OV1 satellite is essentially a non-magnetic vehicle, opening the way to a more varied range of experimental payloads.

And, because the satellite is free of any electrical or electronic links with the propulsion module or booster, it can be flown independently aboard a number of launch vehicles.

Telemetry - A PCM/FM subsystem providing a serial stream of 256 eight-bit words at a rate of 2,048 bits per second. Telemetry data is transmitted in the 216 to 260-MHz band. An 18-hour binary time code generator is provided for data correction. The subsystem also includes a 64-channel submultiplexer; supercommutation can be achieved by external cross-strapping.

Data Storage - A PCM magnetic tape recorder subsystem with a recording capacity at specified rates of up to four hours. Upon command, stored data is played back and transmitted at a 16.1 time compression ratio.

Command - A control subsystem made up of the command receiver, decoder, and logic. The receiver, operating at 400 MHz, receives and FM carrier modulated by dual-audio tone commands. The decoder and logic units identify a valid command and distribute power to perform the commanded switching. The system handles 20 different commands, seven for spacecraft operations, and thirteen for experiment control.

Stabilization - For experiments that require attitude stabilization with respect to the Earth, a vertistat gravity-gradient device damps out random motion and stabilizes the satellite in the earth's gravitational field. Magnetic and spin stabilization systems have also been used for OV1 missions.

Temperature Control - Because the satellite is designed to accept a variety of payloads without change to the basic system, the central payload section is isolated thermally and physically from the end compartments. Temperature control of all compartments is passive, with radiative and conductive balance maintained between the internal packages and the external shell.

Experiment Mounting - Mounting shelves are tailored to the requirements of each specific payload, using longitudinal, conical, or transverse shelving as necessary. Cutouts in the satellite skin can be made as required to accommodate experiment packages with view-angle requirements.

Retrieval/Maintenance (OV2 1/LCS 2 - Payload Failed to Release, Nose Failing, System Failed)

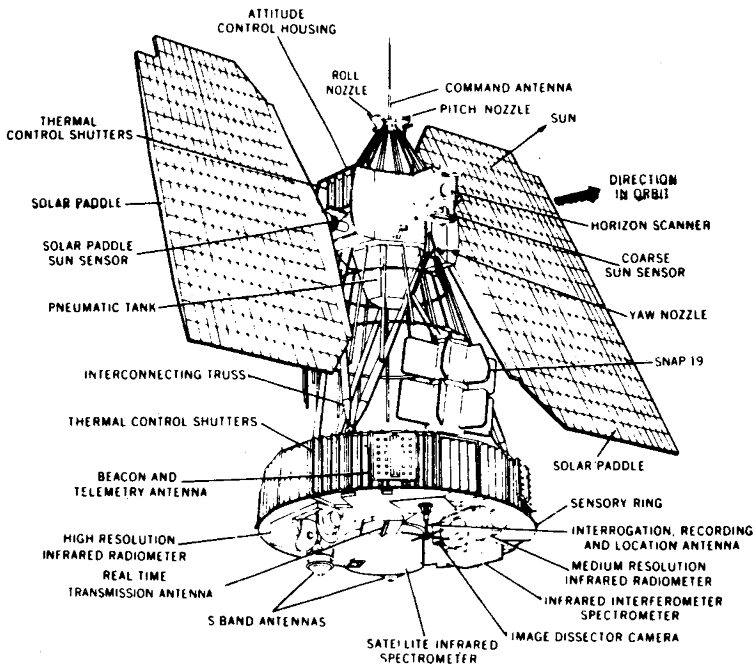
Retrieval:

- Remove Appendages

Maintenance:

- Release payload (in this specific case)
- Repair solar panels
- Replace Batteries (removal of sub-structure)
- Replace magnetic tape recorder
- Experiment instrumentation replacement
- Replace AC engine
- Refuel propellant

REFERENCE 5



NIMBUS PROGRAM (NIMBUS 3)

Spacecraft Description

Like Nimbus 1, 2 and B1, Nimbus 3 is composed of three major elements; a 5-foot-diameter sensory section, a hexagonal upper section, and two 8-by-3-foot rotating solar panels. Upper and lower sections are connected by a truss structure. Sensory ring, a hollow circular section, contains all the weather-measuring experiments as well as spacecraft batteries, transmitters, and associated electronic equipment. Stabilization and attitude control subsystem, housed in upper section is Earth oriented and stabilized within one degree on three axes. Spacecraft is 10 feet high, 11 feet across the solar panels. Weight: a heavyweight record for meteorological satellites, 1269 pounds.

Retrieval/Maintenance

Retrieval:
- Remove appendages
- Remove rotating solar panels
- Remove: Real time transmission antenna
  S-Band antennas
  Interrogation, recording and location antenna
  Command antenna
  Beacon and telemetry antenna

Maintenance:

- Repair: Solar panels
  Solar panel rotating mechanism
  Thermal control shutters
- Replace: Antennas (noted above)
  Horizon scanner
  Coarse sun sensor
  High and medium resolution infrared radiometer
  Infrared spectrometer
  Image dissector camera
  Solar paddle sun sensor
- Remove protective lens cover
- Replace AC nozzles
- Propellant refuel
- Replace batteries

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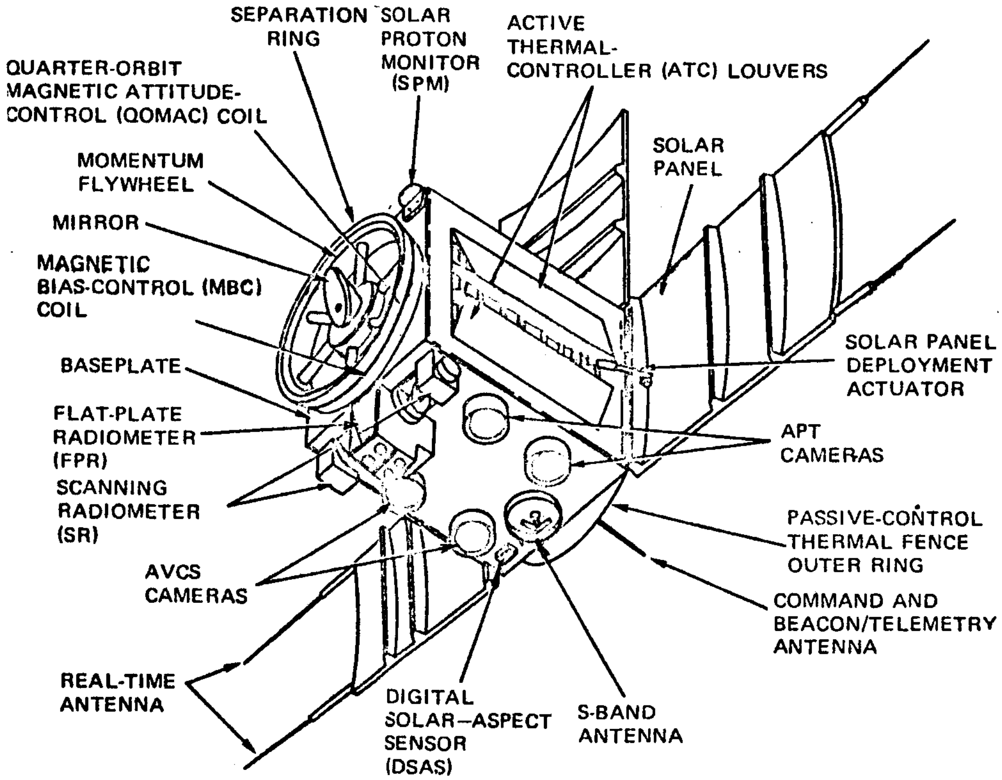
REFERENCE 6



TELEVISION AND INFRARED OBSERVATION SATELLITE (TIROS) (FIGURE IS OF AN IMPROVED TIROS)

Retrieval/Maintenance

Retrieval:
- Remove appendages
- Retract solar panels (repair mechanism if required)

Maintenance:

- Replace: Scanning Radiometer - SR Processor, Magnetic Tapes
  Pitch Control - Pitch Horizon Sensors, Pitch Index pulse generator, Servo Motor
  Roll-Yaw Control - Roll Horizon Sensors, Nutation Dampers
  AVCS - Magnetic Tape Recorders, Associated Elect.
- Data Format Converter
- Incremental Tape Recorder
- Batteries
- Solar Panels
- Antennas
- Repair: Solar Panels
  Thermal Control Louvers

5.0 SHUTTLE EVA CONTAMINATION STUDY

5.1 Scope

The sensitivity of Shuttle payload experiments to contamination is a driving factor in establishing EVA equipment requirements. This study identifies the significant contamination modes, summarizes payload contamination sensitivity, and assesses the significance of these findings on EVA equipment design and use.

5.2 Objective

The objective of this study is to identify any contamination problems associated with EVA equipment.

5.3 Summary

Utilizing sources of data such as the NASA Blue Book and the General Dynamics RAM Study, all the payloads listed in the March 21, 1972 NASA/DOD Shuttle Traffic Model were evaluated in detail to determine their contamination sensitivity. As a result of this investigation, eighty-five (85) of the total of 677 NASA and DOD Shuttle flights were estimated to be transporting contamination sensitive payloads.

On seventy-eight (78) of these flights, the payloads are sensitive to particulate deposition only. On seventy-three (73) of these seventy-eight (78) flights, the contamination sensitive payloads are astronomy free flyers. On these payloads, the experiment package utilizes contamination shields which normally remain closed whenever the Shuttle is in the immediate area and are not opened until forty-eignt (48) hours after the Shuttle leaves the area. Since it takes from one (1) to thirty-five (35) hours for particulate to clear before an experiment can be activated, contamiantion will not normally pose a problem for these payloads. On the remaining five (5) flights which carry payloads that are sensitive to particulate contamination only, special precautions are required. The instrumentation shields must be closed during EVA on these flights and a waiting period of one (1) to thirty-five (35) hours are required before the experiment can be activated.

On the remaining seven flights, three (3) are sensitive to particulate contamination and all seven (7) are sensitive to water vapor contamination. The payload instrumentation shields must be closed during EVA on these flights to avoid

5.3 Summary - Continued

payload contamination. Although a PLSS water umbilical could be used to eliminate the major source of water vapor, the water vapor contained in the EVA suit leakage and/or orbiter leakage is enough to contaminate these payloads.

A general conclusion of this effort is if the payload instrumentation shields are closed during EVA operations which are near contamination sensitive payloads, an Apollo-type EVA system using water as a thermal control subsystem evaporant and having a suit gaseous leakage rate of 100 scc/min. is a useable system for performing Shuttle EVA missions.

5.4 Recommendations

a) The amount of particles shed by an orbiting vehicle, a payload or an EVA astronaut is not actually known. It is also not known how much of this particle flux will adhere to an optical surface, and what is a sufficient distance for non-adhering particles from a vehicle to exert no deleterious influence on measurements being taken. It is recommended that these areas be investigated on earth or in the Skylab program to provide realistic maximum limits for particle shedding by external equipment, and that these limits be correlated to some test procedure or cleanliness level that can be measured on earth prior to launch.

5.5 Discussion

5.5.1 Study Logic

The logic flow of this study is shown in Figure A5-1.

5.5.2 Payload Characteristics

Utilizing the NASA Blue Book and the results of the RAM Study, payload characteristics were identified, specifically addressing contaminant sensitivity, types of instruments used, and the payload use configuration. The NASA Blue Book identifies the scientific objectives sought by orbital

5.5.2 Payload Characteristics - Continued

experimentation and contains concepts of instruments for obtaining them. The RAM payload study is primarily concerned with defining the manned and man-tended scientific payloads to be placed by Shuttle into earth orbit. It contains detailed concepts for grouping the scientific instruments into payloads, and identifies supporting equipment, operational temperature and configuration, and contaminant sensitivity.

The RAM and LST studies state that the highly sensitive energy sensors and their associated analyzers are expected to operate satisfactorily if assembled, tested, and cleaned in a class 10,000 area, and then operated in space. Field and mass sensors and normal-light optics are less sensitive, being operable in space after processing in a class 100,000 area. The IR sensors and other detectors that operate at near absolute zero are sensitive to film deposition exceeding a molecule in thickness.

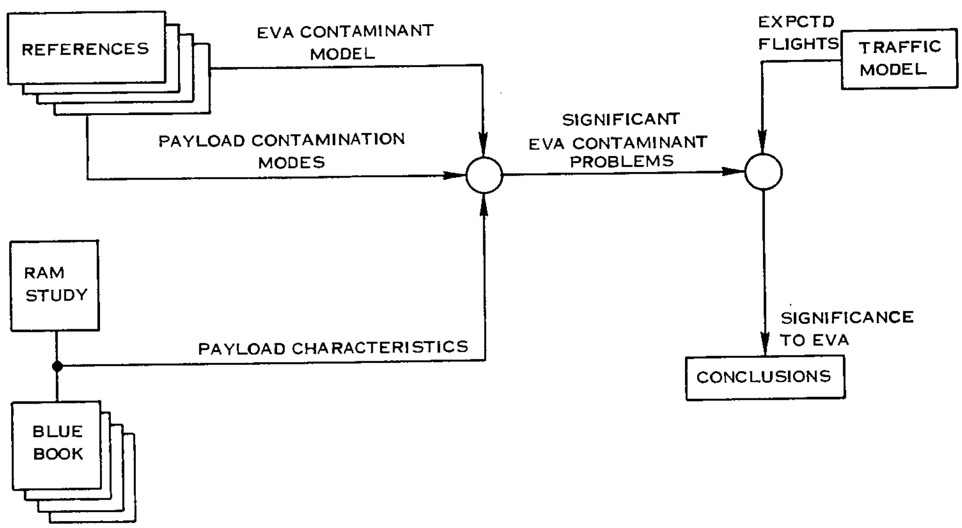


FIGURE A5-1. STUDY LOGIC

The RAM study also identifies 171 experiments that meet the scientific objectives of the Blue Book. Review of the Blue Book indicates that 77 of these experiments are sensitive to contamination as shown in Figure A5-2. The RAM study identifies the contaminants of conern being particles and condensables such as water and organics.

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5.5.2 Payload Characteristics - Continued

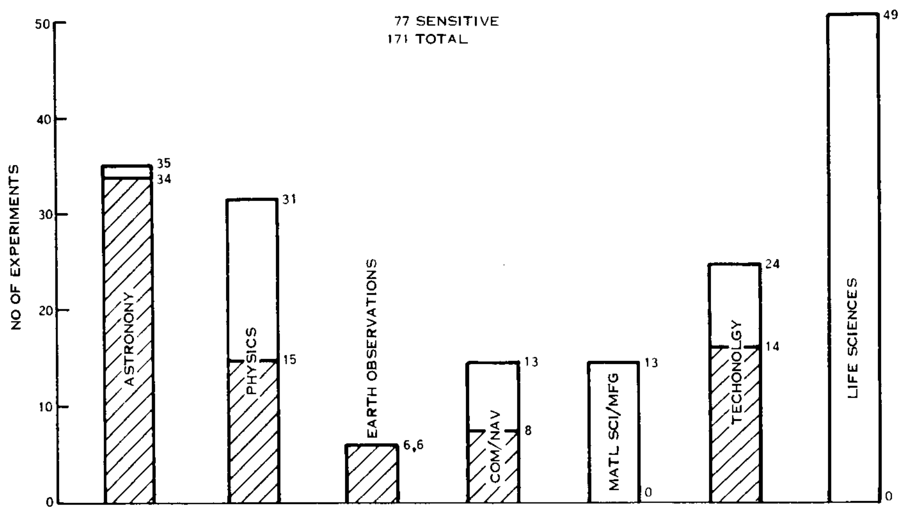

FIGURE A5—2. EXPERIMENT CATEGORIES

The Blue Book is divided into seven categories; astronomy, physics, earth observations, communications/navigation, material science and manufacturing, technology, and life sciences. As shown in Figure A5-2, all or most of the astronomy and earth observation experiments are sensitive to contamination, navigation and technology experiments are sensitive. None of the material science and manufacturing and life science experiments are contamination sensitive. This study does not consider these non-sensitive experiments further.

5.5.3 Astronomy Payloads

The RAM study identifies two types of astronomy payloads that may involve Shuttle EVA: free flyers and Shuttle sortie labs. A free flyer is a large payload instrument placed into orbit by Shuttle for 2 to 10 years, and is revisited for service approximately every 6 months. During free flight periods, it is unmanned. During service periods it is docked to Shuttle and a variety of manned service operations are performed including RCS package replacement which refuels the free flyer, replacement of obsolete or malfunctioned instruments, and replacement of contaminant monitors. Some of these may be performed in an EVA mode and others are expected to be performed in a shirtsleeve mode.

5.5.3 Astronomy Payloads - Continued

The LST free flying RAM, Figure A 5-3 is typical of free flyers in that energy gathering surfaces are located in an unpressurizable area, at the aperture behind a deployable environmental protection shield. The shield is closed well before the Shuttle enters the vicinity of the free flyer.

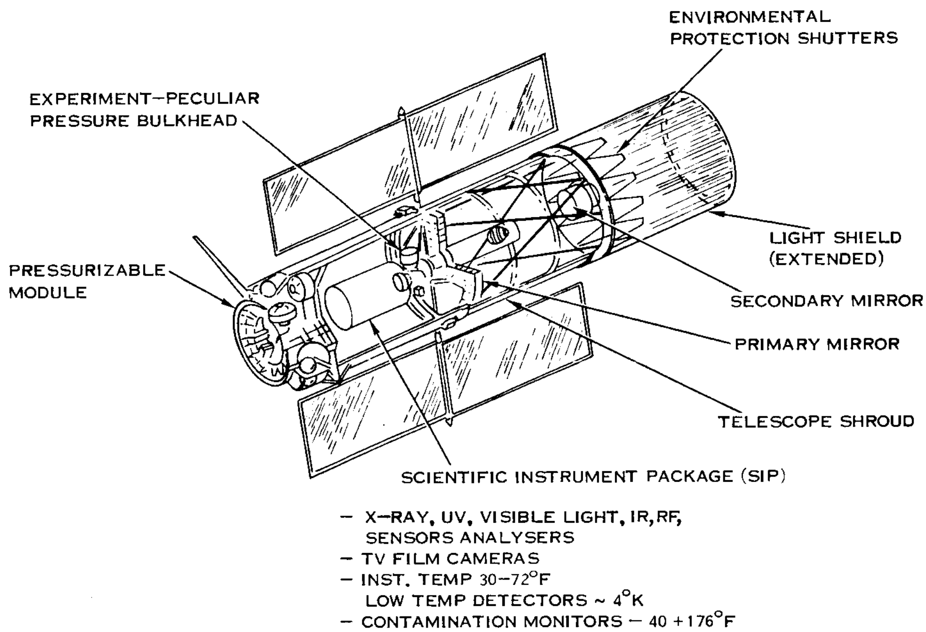

FIGURE A5-3. TYPICAL FREE-FLYING RAM - - LST STELLAR ASTRONOMY

A group of instruments in the focal plane is called the Scientific Instruments Package (SIP). These convert the energy to scientific information. The SIP is located within a pressurizable module to which the Shuttle docks. SIP instruments can be serviced by shirtsleeve operations. Depending upon the payload, the SIP and energy gathering surfaces are controlled within a T of ± 2°F in the range of 30-72°F. These instruments and surfaces have slight to moderate sensitivity to particles in excess of Class 10,000, and will not condense water vapor. Externally-mounted instruments that are not temperature controlled, such as contamination monitors, are expected to range in temperature between -40 to + 176°F as they pass in and out of the sun light. Some of these free flyers also contain energy detectors that operate at 4°K, and are highly sensitive to water vapor deposition when the shields are open. Hence, the astronomy free flyers are not sensitive to EVA contamination unless service is required within the aperture shield. Then optical surfaces may be degraded by particles and very cold surfaces degraded by water vapor deposition.

5.5.3 Astronomy Payloads - Continued

A Shuttle sortie lab remains attached to the Shuttle during a 7 - 30 day flight. No normal EVA assocciated with these payloads is baselined in the RAM study, although several contingency EVA tasks have been identified by Hamilton Standard, including cleaning, instrument element replacement, and shield deployment and retraction. A typical astronomy sortie RAM, Figure A5-4 consists of one or two arrays of sensors, gimbal-mounted to an open pallet. The experiments are operated by a crew within the sortie RAM. The gimballed instruments are shielded against contamination, and are temperature-controlled within $\pm$ 2°F within a band of -5 to +83°F depending upon the payload. The surfaces have slight to moderate sensitivity to particles in excess of Class 10,000 and will not condense water vapor. The externally mounted contamination monitors are uncontrolled, and are expected to range in temperature from -40 to +176°F. Low temperature LR detectors are present on some sortie RAM's, and operate at 4°K. These are highly sensitive to water vapor deposition when the shields are open.

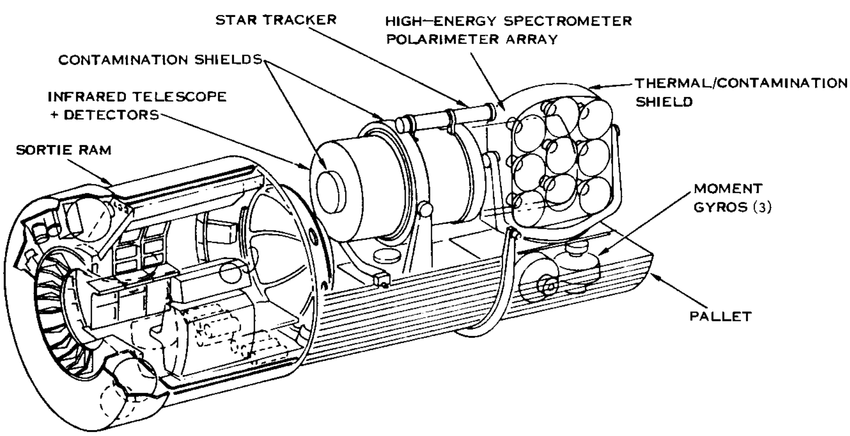

FIGURE A5-4. TYPICAL ASTRONOMY SORTIE PAYLOAD

Thus the astronomy sortie payloads are not EVA contaminable unless service is required within the shield or with the shield open. Then optical surfaces may be degraded by particles, and very cold surfaces may be degraded by water vapor deposition.

5.5.4 Physics Payloads

The physics sortie RAM payloads, Figure A5-5, consist of a RAM support module and payload module, both manned. All instruments are stored within the payload module or airlocks. Those used externally are deployed through the airlocks on the ends of booms, which are 10, 40 and 160 feet long. Instruments consist of fields, particles and energy sensors plus associated analyzers, small optical telescopes, and TV and film cameras. All instrument operation is performed from within the modules. Use duration is on the order of hours, so EVA during experiment use periods is not anticipated. Instrument cleaning, calibration, and other service can be performed within the module in shirtsleeves. Hence the physics payload sorties are not expected to be contaminated by Shuttle EVA.

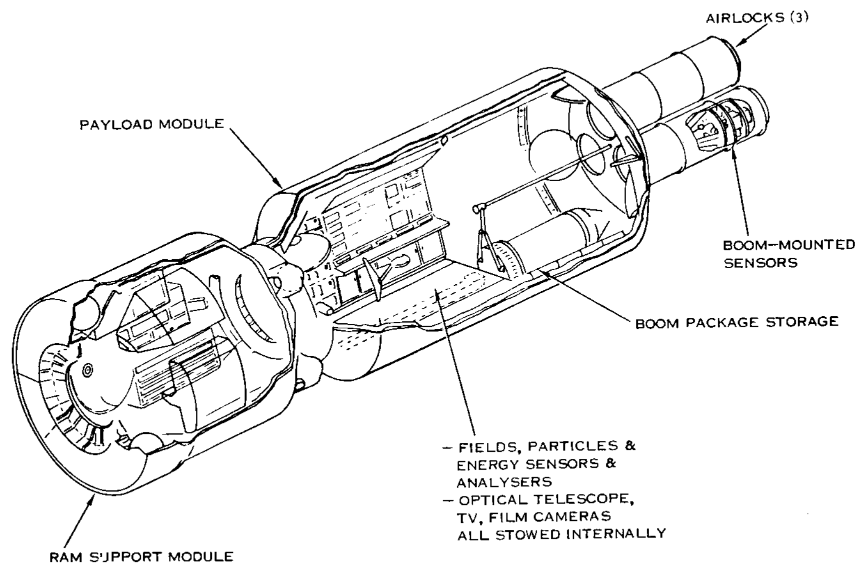

FIGURE A5–5. RAM PHYSICS PAYLOAD

5.5.5 Earth Observations and Communications/Navigation Payloads

Earth observations and communications/navigation payloads, Figure A5-6, consist of a manned sortie RAM plus external instruments supported and deployed from a pressure bulkhead. Externally mounted optical IR and UV instruments are shielded. Other sensors are mounted internally, and view the earth through windows. The windows are also equipped with external shields.

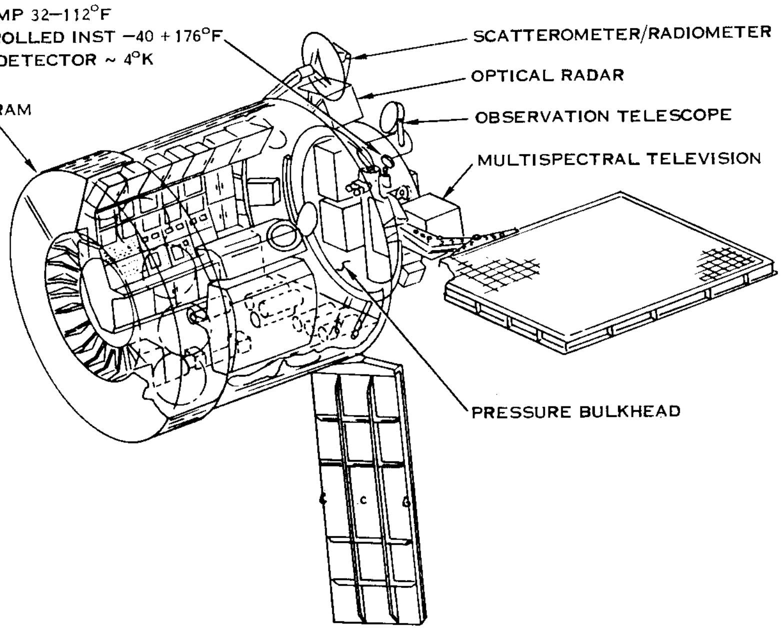

FIGURE A5–6. RAM EARTH OBSERVATION AND COMMUNICATION/NAVIGATION PAYLOAD

Temperature control is maintained on some instruments in the +32°F to 112°F range, depending upon the particular payload. Uncontrolled instruments are expected to range from -40°F to + 176°F. These will not condense water vapor and have slight to moderate sensitivity to particles in excess of Class 100,000. Some of the earth observation payloads carry a multispectral radiometer, which is cooled to 4°K. This is highly sensitive to water vapor deposition when the shield is open.

Some of these payloads call for deployment of large antenna arrays. Unscheduled EVA assistance may be required during deployment and retraction of the antennae and instrument shields. Hence the Communications/Naviagation and Earth Obs Observation payloads are not EVA contaminable unless service is required in the vicinity of an unshielded sensor.

5.5.6 Technology Payloads

Technology experiments are flown mostly as piggyback payloads on other flights, although the Maneuvering Work Platform (MWP), Teleoperator and Astronaut Manevering Unit (AMU) each fly as a combined payload and support module. In piggyback payloads, the experiments are "suitcase carry-ons", with external instruments deployed through airlocks. Hence these instruments are serviceable by shirtsleeve operations upon return to the spacecraft. Some experiments such as leak detection, maintainable attitude control propulsion system, contamination measurement, and active cleaning techniques are performed by EVA. However, the equipment design precludes EVA contamination by shielding and close coupling of signal source and sensor.

The MWP, AMU and Teleoperator payloads use externally deployed normal light cameras, which have lens covers. These instruments can be cleaned by shirtsleeve operations and hence are not likely to be degraded by EVA contaminants. Care should be taken not to direct the AMU or MWP exhause directly at the lenses at close range as the non-water constituents of the exhause may degrade optical coatings.

Hence the technology experiments are not expected to be degraded by EVA contamination owing to the design of the instruments the astronaut uses in space and the ability to clean instruments by shirtsleeve operations.

5.5.7 Payload Characteristics Summary

The payload instruments carried on flights on which Shuttle EVA may be performed are thus seen to consist essentially of three groups:

a) Low energy sensors operating at -5°F or above, sensitive to particles in excess of Class 10,000.

b) TV and film cameras, and mass sensors operating at -40°F or above, sensitive to particles in excess of Class 100,000.

c) Energy detectors operating at approximately 4°K, sensitive to deposition of condensables in excess of one monolayer.

5.5.7 Payload Characteristics Summary - Continued

The instruments stowed internally are considered to be no problem from an EVA contamination viewpoint because they are deployed for relatively short times (hours) and can be cleaned, serviced, and calibrated by shirtsleeve operations after retrieval. Even if contaminated by EVA during a particular use period, they can be returned to operational status by shirtsleeve service in flight.

All of the externally-stowed instruments are shielded. Hence EVA in the vicinity is no problem if the shields are closed during EVA. The only potential problem occurs if EVA is required near a sensor shose shield is open.

5.6 EVA Contaminant Model

From the following references, a model of EVA contaminant generation was formulated, identifying type and quantity of contaminant. These are summarized in Table A5-1.

The human trace gas generation model from the SSP Program identifies the quantifies trace gas production. Air force data on material off-gassing is the data source for identification and quantitication of EVA off-gassing products. The Apollo contamination control handbook is the source of particulate and droplet sizes.

SOLIDS			
DUST 0.3 - 30 DIAMETER			
LINT 40 - 150 LONG			
METAL PARTICLES 30 - 500 DIAMETER			
SHEDDING RATE IN SPACE IS UNKNOWN			
LIQUIDS			
EVAPORANT CARRY-OVER 1 - 50 DIA FOG			
UP TO 10% OF EVAPORANT (DEPENDS ON HEAT SINK TYPE)			
GASSES			
EVAPORANT	H_2O	6.9 LB / 4 MAN-HR	@ 1000 BTU/HR METABOLIC
LEAKAGE @ 100 SCC/MIN	O_2	0.031	
	N_2	0.030	
	H_2O	0.0022	
	CO_2	0.0017	
TRACE GAS		0.000033 / 0.065 LB / 4 MAN-HR	ORGANICS, H_2, NH_3
OUTGASSING		4.8×10^{-6} LB / 4 MAN-HR	ORGANICS CO

TABLE A5-1. EVA CONTAMINANT MODEL

5.6.1 Solids

Solid contaminants consist of the following:

a) The dust source is duct particles liberated from within fabric interstices. The expected size range is from 30 microns in diameter.

b) Lint comes from the deterioration of outer fabric and lint fibers range from approximately 40 to 150 microns long.

c) Metal particles are generated by use of tools and other EVA activity involving metal-to-metal contact. These are expected to range from 30 to 500 microns in diameter.

There is no meaningful data in the literature on the quantity of particles liberated by EVA in space. Hence this must be handled qualitatively in this study.

5.6.2 Liquids

Carry-over of liquid in the evaporant vapor depends upon heat sink type. Apollo and test experience indicates that sublimators have zero carry-over, boilers have approximately 5%, and the flash evaporator, up to 10%. The droplet size is expected to be 1 to 50 microns in diameter, the size of fog droplets.

5.6.3 Gasses

At 1000 Btu/Hr metabolic load, an Apollo PLSS rejects heat at an averate rate of 1700 Btu/Hr, discharging 6.9 lb. of H_2O in a four hour EVA period. Leakage quantities are based upon EVA suit leakage at 100 scc/min which is considered to be the minimum practical specification leakage value for an 8.0 psia system. For comparison, the Apollo EMU leakage was 200 scc/min.

5.6.4 EVA Contamination Modes Summary

Table A5-2 gathers the EVA contaminants into the same groups as payload contamination sensitivity - particles, water and organics, and expresses them in lb/hr.

5.6.4 EVA Contamination Modes Summary - Continued

EVA CONTAMINANT MODEL SUMMARY			
PARTICLES	-	0.5-500	
H_2O	-	1.72 LB/HR.	EVAPORANT
		5.4×10^{-4} LB/HR.	LEAKAGE
GASSES	-	0.0158 LB/HR	LEAKAGE
ORGANICS	-	9.5×10^{-6} LB/HR.	TRACE OFFGASSING

TABLE A5-2. EVA CONTAMINANT MODEL SUMMARY

5.7 Payload Contamination Modes

The following references define the modes by which payloads may become contaminated in orbit and provide the basis for calculating the significance of contamination from EVA sources. The NR payload sensitivity analysis identifies payload contamiantion sensitivity modes. The work of Dr. Naumann of MSFC is the basis for calculations concerning water deposition and dispersal. The RAM study contamination analysis is the basis for calculations of particule dispersion by atmospheric drag.

The contamination modes are:

a) Deposits on sensors which includes particles, water and other condensables.

b) Contamiantion of the local environment which is caused by material in the vicinity of instruments that is not normally present. For this study the local environment is considered to be an area 40 feet from the sensor, which is equivalent to the intermediate boom length of the physics payloads.

5.7 Payload Contamination Modes - Continued

c) Scattering which is the deflection of photons from distant sources on their way to the sensors in orbit.

d) Absorbtion which is an atomic or molecular phenomenon in which specific energy wave lengths are selectively absorbed as they pass through clouds of contaminant gasses, and emission of IR energy by particles, if warm.

Scattering, absorbtion and emission take place both within the local Shuttle environment and out many miles, and may continue until contaminants are left behind, out of sight, and over the horizon.

5.7.1 Particles

5.7.1.1 Deposition

Particle desposition obscures optical surfaces degrading the quality of images formed. Once deposited, particles tend to bond permanently by static electricity. They must be removed by active cleaning. Because the amount of particulate is unknown, it is treated as a potential problem in this study, but only to instruments whose shields are open during EVA.

5.7.1.2 Local Contamination

Local contamination causes spurious inputs to particle sensors. At 100 - 300 miles altitude, the dominant dispersal particle mechanism is atmospheric drag. As shown below, the time to clean a 40 foot area is only seconds to minutes, therefore, particulate in the local area is not expected to be a problem. If the shields remain closed for approximately three minutes after the EVA crewman leaves the area, no spurious inputs should occur.

Particle Size	Altitude	Estimated Time to Clear 40 Foot Area
.5	100 nmi	1.8 sec.
100	100 nmi	7.8 sec.
5	300 nmi	50 sec.
100	300 nmi	181 sec.

5.7.1.3 Scattering, Absorbtion and Emission

Atmospheric drag causes particles beyond the local area to become drawn out in a long, comet-like wake. Measurements taken through the wake are subject to scattering, which reduces source brightness and raises background light levels, making dim light photography difficult. Reflected light from particles resembles faint stars, confusing star trackers, and warm particles emit infra red energy not normally present, confusing the IR sensors.

Measurements taken in directions away from the particle wake are not affected by distant particles. Distant particles pose problems only when measurement are taken in the direction of the wake. Depending upon particle size and orbital altitude, it takes atmospheric drag from 15 minutes to approximately 35 hours to sweep particles out of sight and over the horizon as shown below:

Particle Size	Altitude	Estimated Time to Sweep Particles Over Horizon
5	100 nmi	15 min.
30	100 nmi	36 min.
100	100 nmi	66 min.
5	300 nmi	9.4 hr.
30	300 nmi	21.1 hr.
100	300 nmi	34.4 hr.

To gain perspective on the particle-shedding question, other sources of particles are examined. A payload assembled and tested in Class 10,000 can accumulate upwards of 600 particles/in^2/day. Hence a payload may accumulate many particles and shed some or all of these in orbit.

The surface area of an EVA crewman is on the order of 1/500 that of the orbiter vehicle. The vehicle is expected to be unprotected during turn-around on earth, hence will be exposed to particles and dust. Flight control surfaces, payload bay doors and the payload bay itself are of complex shape. It is difficult to establish and maintain cleanliness of these surfaces. Hence, the orbiter also is expected to accumulate many particles and shed some or all of these in orbit.

5.7.2 Water

5.7.2.1 Deposition of Water

The effect of water deposition is to freeze on cold surfaces, thus obscuring the sensor. Deposition of water by condensation is a complex physical phenomenon governed by surface temperature and by water flow rate and distance from source to sensor. These latter two define flux or flow rate per unit area through a normal surface at a given distance away from the source. For every distance from a water vapor source discharging at a given rate, there is a satruation temperature above which water will not condense. Since flux decreases with distance, this minimum temperature also decreases with increasing distance.

For an astronaut working one-to-two feet away from a sensor, and wearing an Apollo type PLSS venting water at 1.72 lb./hr., no condensation will occur if the sensor is above -70°F. If the sensor is at -40°F, the minimum temperature expected for uncontrolled sensors, the PLSS can be as close as .33 feet. However, if a sensor is at -189°F (150°K), condensation will occur if the PLSS is within 450 feet.

Stay-time of water molecules in a monolayer on a sensor is another way of looking at deposition. As shown below, the stay time for temperatures above -40°F is micro-seconds. At 150°K (-189°F) the time lengthens to 35 seconds, and at only 50°K, that lengthens drastically to over 600 years. This is permanent with respect to a 10 year orbital life. At cryogenic temperatures, the stay time is billions of years. For practical purposes, stay times at above 150°K are insignificant and below 150°K become infinite.

Temperature	Stay Time	Remarks
-5°F (253°K)	0	Telescope Optics Temp.
-40°F (233°K)	20×10^{-6} Sec.	Uncooled Sensor Min. Temp.
-189°F (150°K)	35 Sec.	H_2O Becomes Problem
-280°F (100°K)	260 Years	Permanent Deposit
-452°F (4°K)		I.R. Sensor Temp.

5.7.2.1 Deposition of Water - Continued

Another way of looking at water deposition is to calculate the time required to form a monolayer at a practical working distance such as two feet. From the figures below, it can be seen that at less than 150°K the time required to form a monolayer at a two foot distance is so short as to preclude any meaningful service task with the instrument shield open, regardless of system-type used.

H_2O Flow		Distance	Time
EVA Leakage	5.4×10^{-4} $\frac{lb}{hr}$	2 feet	21 Seconds
Venting PLSS	1.72 $\frac{lb}{hr}$	2 feet	.0007 Seconds

Even working in the vicinity of an unshielded, cold sensor for relatively short times poses problems. The figures below show that to perform an EVA of one-half hour duration requires that the astronaut remain a significant distance from such an instrument. Hence, if EVA is required in the vicinity of such sensors, the shields should be closed.

EVA Leakage Flux, 5.4×10^{-4} $\frac{lb}{hr}$	19 feet
Venting PLSS Flux, 1.72 $\frac{lb}{hr}$	3280 feet

To gain perspective on the water deposition question, the cabin water leakage source is considered. At .0185 lb/hr leakage, there is sufficient water vapor flux from the cabin to cause deposition on cold sensors in one-half hour within a distance of 294 feet. Therefore, unshielded cold sensors must not face the cabin or intercept the cabin water flux when the shields are open.

5.7.2.2 Local Contamination, Scattering and Absorbtion

If the evaporant discharge contains some liquid carry-over, a portion of liquid is expected to form ice crystals, which are very effective light scatterers. The water vapor absorbs energy in discrete spectral bands. Both vapor and ice within the local environment will produce spurious inputs to mass sensors. Ice crystals disperse by sublimation and atmospheric drag. Water vapor disperses by molecular diffusion.

5.7.2.2 Local Contamination, Scattering and Absorbtion - Continued

However, Apollo 15 Contamination Photography indicated that the liquid, vapor, and ice crystals formed by Apollo urine dumps dispersed and cleared in approximately one-half hour after dumping ceased under the influence of sublimation and molecular dispersion. Because these dumps took place in cislunar orbit, atmospheric drag played no significant part. Thus it is a conservative estimate that EVA water vapor and ice crystals will clear within one-half hour after the astronaut returns to the cabin. Thus to avoid erroneous data, data taking may require a one-half hour wait after completion of EVA.

To gain perspective in the water discharge question, other water discharge sources are considered. Fluid discharge is not unique to EVA. During periods of active attitude control, the Shuttle Payload Contamination Sensitivity Analyses indicates that the Orbiter will discharge 50 lbs/hr of effluent (including NH_3, & H_2O) from the Attitude Control Propulsion System (ACPS) to maintain the nominal $1/2^{o}$ angle 3-axis dead band. Experimental equipment and operational procedures must accommodate periods of ACPS operations. At 1.72 lb/hr, the PLSS discharge is only 1/30 of the ACPS. Hence EVA is not expected to pose problems of local contamination, scattering, absorbtion and emission by water apart from the Orbiter.

5.7.3 Gasses and Organics

5.7.3.1 Deposition

As shown below, the EVA gasses all have low condensation temperatures, and hence will not condense on the uncolled sensors. At .016 lb/hr, the leakage gasses are approximately 1/100 of the evaporant discharge rate, and with the low gas condensation temperature, the gasses are expected to be no problem apart from the evaporant discharge.

CO_2	$-160^{o}F$
N_2	$-297^{o}F$
O_2	$-321^{o}F$

The EVA leakage gas is only 1/25 of the cabin leakage of 0.4 lb/hr, and hence is no problem apart from the Orbiter.

5.7.3.1 Deposition - Continued

The organics also have low condensation temperatures, and will not condense on uncooled sensors at -40°F min. They may condense on very cold surfaces, but at only 1/60 of the EVA water leakage, they pose no problem apart from the leakage water.

5.7.3.2 Absorbtion Scattering

These gasses are inefficient absorbers and scatterers of incident energy, hence are not expected to pose a problem in this regard.

5.7.4 Summary of Significant EVA Contaminants

Table A5-3 summarizes the problem areas caused by EVA contaminants for each of the modes of experiment contamination. As can be seen, the principal contaminants are particles and water vapor as they affect sensors with the shields open.

CONTAMINANT/MODE SUMMARY				
	DEPOSITION	LOCAL CONTAMINATION	SCATTERING	ABSORPTION EMISSION
PARTICLES	LOW ENERGY SENSORS-	NO PROBLEM CLEAR IN 3 MIN.	LOW ENERGY SENSORS- CLEAR IN 1-35 HR.	LOW ENERGY SENSORS- CLEAR IN 1-35 HR.
WATER VAPOR	SENSORS 150°K	NO PROBLEM CLEAR IN 1/2 HR.	NO PROBLEM CLEAR IN 1/2 HR.	NO PROBLEM CLEAR IN 1/2 HR.
EVA LEAKAGE	NO PROBLEM APART FROM ORBITER	NO PROBLEM	NO PROBLEM	NO PROBLEM
OUTGASSING	NO PROBLEM APART FROM WATER VAPOR	NO PROBLEM	NO PROBLEM	NO PROBLEM

TABLE A5-3. EVA CONTAMINANT/MODE SUMMARY

5.8 Significance to EVA

At this point in the study, the significant EVA contaminant problems have been identified. To assess the impact of these problems on the Shuttle program requires determination of the relative frequency that these problems occur.

The RAM Payload Study groups the Blue Book Experiments into payloads of related scientific interest for delivery into a particular orbit. The 171 total Blue Book experiments are grouped into 62 RAM payloads, and the 77 contaminant-sensitive experiments comprise 46 sensitive RAM payloads. These payloads are shown in Table A4-4. However, there is a mismatch between the RAM payloads and the Shuttle Traffic Model such that some RAM payloads are not included in the Traffic Model, hence are not expected to fly. Of 46 sensitive RAM payloads, only 39 are identified in the Traffic Model. These are also shown in Table A5-4.

Of the 39 contaminant sensitive RAM's in the Traffic Model, 14 are not susceptible to EVA contamination either because they are Space Station modules (5) or they contain only instruments that are stowed internally (9). These payloads were not considered further in this study. This leaves 25 potentially contaminable RAM's in the Traffic Model. These consist of 14 astronomy payloads, six Earth observation, three communications/navigation and two technology payloads. These are shown in Table A5-4.

The 25 potentially contaminable RAM's remaining may be further subdivided. Those payloads sensitive only to particles at level 10,000 and/or have sensors at 150°K are significantly sensitive. These are the payloads that could place operational or design restrictions upon EVA equipment. There are 19 of these, consisting of 14 astronomy and 5 Earth observations. The six payloads that are not significsntly sensitive consist of three communications/navigation, two technology and one Earth observation payload. These were not considered further in this study.

According to the Traffic Model the significantly sensitive payloads are assigned to flights as follows, and as also shown in Table A4-5.

5.8 Significance to EVA - Continued

Payload Class	Discipline	P/L No.	RAM Payload Title	Mission: Orbit: Preferred	Mission: Orbit: Acceptable	Mission: Orbit: Recommended	Mission: Orientation	Mission: Viewing Constraint	Mission: Pointing Accuracy; Stability	Mission: Point Duration (hr/obs)	Environment: Accel. (g)	Environment: Contam.	Environment: Radiation (rad/hr)	Environment: Temp (K)	Special	Payload in Traffic Model	Contam. Sens RAM Payload in Traffic Model	Shuttle AVA Contaminable Payload in Traffic Model
Sortie	Astronomy	A3S1B	Austere Solar Astronomy (Telescope)	Sun sync, 200 n. mi.	Any within rad limits	97 deg 220 n. mi.	Solar	Sunline 170 km from horizon	10 arc-sec; 0.5-1.0 arc-sec/obs	0.01-0.8	$<10^{-3}$	Particles Organics	$<10^{-3}$	281-284		Yes	Yes	Yes
		A6S1B	Austere IR Astronomy (ARC Telescope)	28-55 deg, 270 n. mi.	0-55 deg, 200-400 n. mi.	40 deg 300 n. mi.	Stellar	45 deg from Sun 30 deg from Earth	1.0 arc-sec; 0.5 arc-sec/obs	0.1-5	$<10^{-3}$	Particles Condensable	$<10^{-3}$	233-313		Yes	Yes	Yes
		A8S1U	Combined Austere Astronomy (ACR) Telescope & High Energy Array)	28-55 deg, 270 n. mi.	0-55 deg, 200-400 n. mi.	40 deg 300 n. mi.	Stellar	45 deg from Sun 30 deg from Earth	1 arc-sec; 0.5 arc-sec/obs	0.1-5	$<10^{-3}$	Particles Condensable	$<10^{-3}$	288-293 233-313		Yes	Yes	Yes
		A8S1V	Combined Austere Astronomy (Solar Telescope & High Energy Array)	Sun sync, 200 n. mi.	Any within rad limits	97 deg 250 n. mi.	Solar, stellar	Sunline 170 km from horizon	10 arc-sec; 0.5-1.0 arc-sec/obs	0.01-0.8	$<10^{-4}$	Particles Organics	$<10^{-3}$	281-284 253-293		Yes	Yes	Yes
		A8S1W	Combined Austere Astronomy (UV Wide Field Telescope & High Energy Array)	<55 deg, >300 n. mi.	<55 deg, >200 n. mi.	40 deg 300 n. mi.	Stellar	60 deg from Sun 15 deg to horizon	5-60 arc-sec; 1 arc-sec/obs	1 sec-1 hr	$<10^{-4}$	Particles Effluents	$<10^{-3}$	289-291 273-300		Yes	Yes	Yes
		A8S1X	Combined Austere Astronomy (UV Narrow Telescope & High Energy Array)	<5 deg, 400-500 n. mi.	<55 deg, 200-400 n. mi.	40 deg 300 n. mi.	Stellar	60 deg to Sun 25 deg to horizon	1 arc-sec; 1.0 arc-sec/obs	0.2-0.8	$<10^{-4}$	Particles Effluents	$<10^{-3}$	288-290 250-293		Yes	Yes	Yes
		A8S1Z	Combined Austere Astronomy (IR Telescope & High Energy Array)	0 deg, 200-400 n. mi.	0-55 deg, 200-400 n. mi.	40 deg 300 n. mi.	Stellar	90 deg from Sun 60 deg from Earth	1 arc-sec; 1 arc-sec/obs	0.75	$<10^{-3}$	Particles Condensable	$<10^{-3}$	253-293 233-313		Yes	Yes	Yes
		A9S1J	Combined Austere Astronomy (Solar Telescope & High Energy Array)	<10 deg, 400 n. mi.	45-55 deg, 270 n. mi.	40 deg 300 n. mi.	Solar	On solar disc 22 deg from horizon	10 arc-sec; 2.5 arc-sec/obs	0.75	$<10^{-3}$	Particles Effluents	$<10^{-3}$	281-284 272-274		Yes	Yes	Yes
	Physics	P5S1B	Combined Space/Plasma Physics (Austere)	Pollar, 100 n. mi.	>50 deg, >100 n. mi.		Earth	None	120 arc-sec; 12 arc-sec/sec	96 continuous	-	Particles Effluents	-	-	Airlock & Booms	Yes	Yes	-
		P5S2A	Combined Space/Plasma Physics (Intermediate)	Polar, 100 n. mi.	>50 deg, >100 n. mi.		Stellar & Earth	Dark	1.6 arc-sec; 0.5 arc-sec/sec	10	-	Particles Effluents	-	-	Airlock & Booms	Yes	Yes	-
		P7S1A	Combined Cosmic Ray Physics & Chemistry (Austere)	28.5 deg <200 n. mi.	Any		Earth	None	1.0 deg; 0.1 deg/sec	10	-	Particles Effluents	-	-	Airlock & Boom	Yes	Yes	-
		P7S2A	Combined Cosmic Ray Physics & Chemistry (Advanced)	<300 n. mi.	Any		Earth	None	1.0 deg; 0.1 deg/sec	1	$<10^{-4}$	Particles Effluents	-	-	Airlock & Boom	Yes	Yes	-
		P8S2B	Combined Space Plasma/Cosmic Ray Physics (Intermediate)	Polar, 100 n. mi.	>50 deg, >100 n. mi.		Earth	None	±120 arc-sec; 12 arc-sec/sec	96 continuous	-	Particles Effluents	-	-	Airlock & Boom	Yes	Yes	-
	Earth Observations	E1S1N	Earth Observation (Weather) - Austere	Polar, 100 n. mi.	50 deg		Earth	±60 deg from nadir	±0.5 deg; 0.01 deg/sec	15 min/obs	$<10^{-5}$	Particles Effluents	-	-		Yes	Yes	Yes
		E1S1O	Earth Observation (World Land Use Mapping) - Austere	Polar, 100 n. mi.	50 deg		Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	25 min/obs	-	Particles Effluents	-	-		Yes	Yes	Yes
		E1S1P	Earth Observation (Air & Water Polution) - Austere	50 deg, 100 n. mi.	50 deg		Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	12 min/obs	-	Particles Effluents	-	-		Yes	Yes	Yes
		E1S1Q	Earth Observation (Resource Location) - Austere	Polar, 100 n. mi.	50 deg		Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	15 min/obs	-	Particles Effluents	-			Yes	Yes	Yes
		E1S1R	Earth Observation (Disaster Assessment) - Austere	70 deg, 100 n. mi.	50 deg		Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	3 min/obs	-	Particles Affluents	-	-	$1. \times 10^{9}$ bits/da near R. T.	Yes	Yes	Yes
		E1S1S	Earth Observation (Ocean Resources) - Austere	Polar, 100 n. mi.	50 deg		Earth	±60 deg from nadir 0.05 deg/sec	±0.5 deg;	15 min/obs	-	Particles Effluents	-			Yes	Yes	Yes
	COM/NAV	C1S1E	Communication/Navigation (Lab I) - Austere	Polar	28 deg-polar		Earth	180 deg	0.01 deg; 1 deg/sec	15 min/obs	-	Particles Effluents	-	-	300 kbps R. T. Trans	Yes	Yes	Yes
		C1S1F	Communication/Navigation (Lab I) - Austere	Polar	28 deg-polar		Earth	180 deg	0.01 deg; 0.1 deg/sec	15 min/obs	-	Particles Effluents	-	-	30 kbps R. T. Trans	Yes	Yes	Yes
		C1S2C	Communication/Navigation (Lab II) - Intermediate	Polar	28 deg-polar		Earth, stellar entry	180 deg	0.01 deg; 0.1 deg/sec	60 min/obs	-	Particles Effluents	-	-	300 kbps R. T. Trans	Yes	Yes	Yes
	Materials Science	M1S1E	MS Configuration 1 - Operations Level 1	Any	Any		-	-	-	-	$<10^{-4}$	-	-	-		Yes	-	-
		M1S1F	MS Configuration 1 - Operations Level 2	Any	Any		-	-	-	-	$<10^{-4}$	-	-	-		Yes	-	-
		M1S1G	MS Configuration 1 - Operations Level 3	Any	Any		-	-	-	-	$<10^{-4}$	-	-	-		Yes	-	-
		M1S2B	MS Configuration 2 - Operations Level 3	Any	Any		-	-	-	-	$<10^{-4}$	-	-	-		Yes	-	-
	Technology	T1S3A	Complete Contamination Measurements	Any	-		Sun Vector	-	0.5 deg; 0.05 deg/sec	14	-	Particles Effluent	-	-	Piggyback	Yes	Yes	-
		T2S1A	Propellant Transfer Experiment	Any	-		-			-	Shuttle ambient	-	-	-		Yes	-	
		T2S2E	Combined Cryogenic Storage & Fluid Systems Experiment	Any	-		-	-	-	-	Shuttle ambient	-	-	-		Yes	-	-
		T3S1A	Astronaut Maneuvering Unit Experiment	Any	-		Stable during EVA	Clear view of exp	-		-	Particles Effluents	-		EVA	Yes	Yes	Yes
		T3S2B	Maneuverable Work Platform Experiment	Any			Stable during launch, retrieval	Clear view of exp	-	-	-	Particles Effluents	-	-	EVA	Yes	Yes	Yes
		T4S1A	Short Duration Advanced Spacecraft Systems Test	Any	-		-	-	-	-	-	Particles Effluents	-	-	Piggyback	Yes	Yes	-
		T5S2B	Teleoperator Experiment	Any	-		Stable during exp	-	-	-	-	Particles	-	-		Yes	Yes	-
		33	RAM Payloads									27 Sensitive RAM Payloads				33	27	19

TABLE A5-4. RAM PAYLOAD SUMMARY DATA

5.8 Significance to EVA - Continued

Payload Class	Discipline	P/L No.	RAM Payload Title	Mission: Orbit Preferred	Orbit Acceptable	Orbit Recommended	Orientation	Viewing Constraint	Pointing Accuracy; Stability	Point Duration (hr/obs)	Environment: Accel. (g)	Contam.	Radiation (rad/hr)	Temp (K)	Special	Payload In Traffic Model	Contam. Sens RAM Payload In Traffic Model	Shuttle AVA Contaminable Payload in Traffic Model
Sortie (Contd)	Life Science	L8S1B	Life Sciences Lab (Mini-7)	0 deg, 250 n. mi.	Any		-	-	-	-	$<10^{-5}$, 95% of time	-	Minimum	-	EVA	Yes	-	-
		L8S2B	Life Sciences Lab (Mini-30)	0 deg, 250 n. mi.	Any		-	-	-	-	$<10^{-5}$, 95 of time	-	Minimum	-		Yes	-	
		L8(D)1A	Bioresearch Module	200 n. mi.	200 n. mi.		-	-	-			-	Minimum	-	Piggyback	-	-	-
Free-Flying	Astronomy	A103B	X-Ray Astronomy Observatory	0 deg 400 n. mi.	0-5 & 28-55 deg 200-300 n. mi.	40 deg 300 n. mi.	Stellar	>45 deg from Sun >22 deg from Earth	1 arc-sec; 1 arc-sec/obs	9.5	$<10^{-4}$	Particles Effluents	$<10^{-3}$	272-274		-	-	-
		A202B	Large Space Telescope	28-5 deg 400 n. mi.	28-55 deg 250-350 n. mi.	40 deg 300 n. mi.	Stellar	≥45 deg to Sun ≥22 deg to Earth	1 arc-sec; 0.005 arc-sec/obs	0.3-6	$<10^{-4}$	Particles Hydrocarbons	$<10^{-3}$	273-275		Yes	Yes	Yes
		A203B	Advanced Stellar Astronomy Observatory	28.5 deg 400 n. mi.	28.55 deg 250-350 n. mi.	40 deg 300 n. mi.	Stellar	≥60 deg to Sun ≥22 deg to Earth	1 arc-sec	0.3-6	$<10^{-4}$	Particles Hydrocarbons	$<10^{-3}$	273-275		Yes	Yes	Yes
		A303B	Advanced Solar Astronomy Observatory	10 deg 400 n. mi.	0-5 & 28-55 deg 270-300 n. mi.	40 deg 300 n. mi.	Solar	0.3 deg of Sun center	1 arc-sec; 0.017 arc-sec/obs	0.75	$<10^{-4}$	Particles Organics	$<10^{-3}$	290-297		Yes	Yes	Yes
		A502D	High Energy Stellar Astronomy Observatory	o deg 400-500 n. mi.	0-5 & 28-55 deg 200-300 n. mi.	40 deg 300 n. mi.	Stellar	≥60 deg to Sun ≥22 deg to Earth	2 arc-sec; 1 arc-sec/obs	0.1-6	$<10^{-4}$	Particles Effluents	$<10^{-3}$	273-277		Yes	Yes	Yes
		A503B	High Energy Stellar Astronomy Observatory	0 deg 400-500 n. mi.	0-5 & 28-55 deg 200-300 n. mi.	40 deg 300 n. mi.	Stellar	≥60 deg to Sun	2 arc-sec/obs	0.1-6	$<10^{-4}$	Particles Effluents	$<10^{-3}$	272-277		Yes	Yes	Yes
		A703A	Large Radio Astronomy Observatory	28-55 deg 35[illegible] n. mi.	28-55 deg 270-400 n. mi.	40 deg 300 n. mi.	Stellar & Solar	≥15 deg from earth horizon	1 arc-sec 1 arc-sec/obs	0.75	$<10^{-4}$	Particles Condensables	$<5 \times 10^{-3}$	292-294		Yes	Yes	Yes
	Technology	T103B	Complete Contamination Measurement	Any	-		-	-	-	-	-	Particles Deposits	-	-	Piggyback	-	-	-
		T2(D)2B	Detached Long-Term Cryogenic Storage Equipment	Sun Sync	Any		Inertial & Earth	-	-	-	Low-g coast	-	-	-		Yes	-	-
		T401A	Long Duration Advanced Spacecraft Systems Test	Any	-		-	-	-	-	-	Particles Effluents	-	-	Piggyback	Yes	Yes	-
Station-Attached	Astronomy	A4A2A	Narrow Field UV Astronomy	28-55 deg 400 n. mi.	28-55 deg 200-400 n. mi.	55 270 n. mi.	Stellar	≥60 deg to Sun >25 deg to Earth	1 arc-sec 1 arc-sec/obs	0.2-0.[illegible]	$<10^{-4}$	Particles Effluents	$<10^{-3}$	288-290		-	-	-
		A6A3A	Austere Astronomy (IR Telescope)	50-60 deg 270-300 n. mi.	25-70 deg 250-400 n. mi.	55 deg 270 n. mi.	Stellar	>90 deg to Sun >60 deg to Earth	1 arc-sec 1 arc-sec/obs	0.75	$<10^{-3}$	Particles Condensables	$<10^{-3}$	272-274		-	-	-
	Physics	P3A3A	Costomic Ray Laboratory	28 deg, 200 n. mi.	55 deg, 270 n. mi.		Away from Earth	No data if viewing Earth	1 deg knowledge; ± 45 deg/obs	Essentially continuous	-	Not Critical	-	-	Thin windows	Yes	-	-
		P6A3A-1	Combined Space/Plasma Physics Laboratory (Complete)	Polar 100 n. mi.	50 deg 100 n. mi.		Earth & Stellar	Dark	1.6 arc-sec 0.5 arc-sec/sec	Continuous	$<10^{-4}$	Particles (slight)	-	-	Airlock & booms	Yes	Yes	-
		P6A3A-2	Physics and Chemistry Laboratory (Complete)	300 n. mi.	Any		Earth	None	1.0 deg; 0.1 deg/sec	10	$<10^{-4}$	Particles (slight)	-	-	Airlock & booms	Yes	Yes	-
	Earth Observations	E1A2B	Intermediate Earth Observations Lab	55 deg, 270 n. mi.	50-90 deg, 100-270 n. mi.		Earth	± 60 deg from nadir*	0.5 deg; 0.05 deg/sec	15 min/obs	-	Particles Effluents	-	-		-	-	-
		E1A3B	Complete Earth Observations Lab	55 deg, 270 n. mi.	50-90 deg 100-270 n. mi.		Earth	± 60 deg from nadir*	0.5 deg; 0.01 deg/sec	25 min/obs	$<10^{-5}$	Particles Effluents	-	-			-	-
	COM/NAV	C1A2B	Communication/Navigation (Lab II) - Intermediate	Polar	28 deg, polar		Earth	360 deg	0.01 deg; 0.1 deg/sec	90 min/obs	-	Particles Effluents	-	-		Yes	Yes	-
		C1A3B	Communication/Navigation (Lab III) - Complete	Polar	28 deg, polar		Earth	360 deg	0.01 deg; 0.1 deg/sec	90 min/obs	-	Sensitive Particles Effluents		-		Yes	Yes	-
	Materials Science	M1A3B	MS Configuration 2 - Operations Level 4	Any	Any		-	-	-	-	$<10^{-4}$	-	-	-		Yes		
	Technology	T1A3A	Complete Contamination Measurement	Any	-		Solar	-	0.5 deg; 0.05 deg/sec	14	-	Particles Effluents	-	-	Piggyback	Yes	-	-
		T4A1A	Medium Duration Advanced Spacecraft Systems Test	Any	-		-			-	-	Particles Condensables	-	-	Piggyback	Yes	Yes	-
	Life Sciences	L8A1B-1	Station Mission (Midi 30, F Module)	0 deg 250 n. mi.	Any		-	-	-		$\leq 10^{-5}$, 95 of time	-	Minimum	-	-	Yes	-	-
		L8A1B-2	Station Mission (Midi 30, BLH Module)	0 deg 250 n. mi.	Any		-	-	-		$\leq 10^{-3}$, 95 of time		Minimum	-	EVA	Yes		-
		L8A2B-1	Station Mission (Maxi Nom, F Module)	0 deg 250 n. mi.	Any		-	-	-		$\leq 10^{-5}$, 95% of time		Minimum			Yes		
		L8A2B-2	Station Mission (Maxi Nom, BLH Module)	0 deg, 250 n. mi.	Any		-	-	-		$\leq 10^{-3}$, 96% of time	-	Minimum	-	EVA	Yes		

29 RAM Payloads
+33
62 Total RAM Payloads

19 Sensitive RAM Payloads
+27
46 Total Sensitive RAM Payloads

Payload In Traffic Model: 22, +33, 55 Tot.
Contam. Sens RAM Payload In Traffic Model: 12, +27, 39 Tot.
Shuttle AVA Contaminable Payload in Traffic Model: 6, 19, 25 Tot.

Data in Table adapted from Ref. 9

TABLE A5-4. CONTINUED

5.8 Significance to EVA - Continued

RAM Payload	Particles only	H_2O	Particles & H_2O	Remarks	MSC Payload No.	Potential Flights Per MSC Traffic Model	Expected Flights of Sig. Sens. MSC Payload	Expected Flights With Water Sensitivity	Expected Flights With Particle Sensitivity
A3SIB*	X				38		1 †		1
A6SIB*			X		38		1	1	1
A8SIU*			X		38		1	1	1
A8SIV*	X				38	16	1	N/A	1
A8SIW	X				38		1	N/A	1
A8SIX*	X				38		1	N/A	1
A8SIZ*			X		38		1	1	1
A9SIJ*	X				38		1		1
CISIE				Particles > cl. 100,000	38				
CISIF					38				
CIS2C					38				
T3SIA				EVA instruments stored individually	38				
T3S2B					38				
EISIN*		X		Particles > cl. 100,000	42				
EISI0*		X			42		1	1	N/A
EISIP*		X			42	4	1	1	N/A
EISIQ*		X			42		1	1	N/A
EISIR*		X			42		1	1	N/A
EISIS					42				
A202B*	X				15	3	3	N/A	3
A203B*	X				16	17	17	N/A	17
A303B*	X				17	2	2	N/A	2
A502D*	X				13	4	4	N/A	4
A503B*	X				14, 18	35	35	N/A	35
A703A*	X				19, 20	12	12	N/A	12
Total 25 (19*)	11	5	3			93	85	7	81

† NOTE: Since MSC payload 38 includes 31 RAMS, it is assumed that each of the 8 significantly sensitive RAMS in payload 38 will fly only once in the 16 flights of payload 38.

* Payloads sensitive to particles > cl. 10,000 or operated at < 150°K

TABLE A5–5. RAM PAYLOADS WITH SIGNIFICANT CONTAMINATION SENSITIVITY

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

5.8 Significance to EVA - Continued

Significant Contaminants	RAM's		Flights	
Particles	11 Astronomy	78	81	Particle Sensitive
H_2O & Particles	3 Astronomy	3		
H_2O	5 Earth Obs.	4	7	H_2O Sensitive
	19			

Hence, out of 677 potential Shuttle flights, the significant payload contamination problems are:

Water deposition on cold sensors with open shields - 7 flights

Particle deposition on sensitive instruments with open shield - 81 flights

Scattering, absorbtion, and emission of low level incident energy by particles - 81 flights

5.8.1 Water Deposition Significance

The significance of water deposition to EVA is that the present expected leakage rate (100 scc/min) is acceptable for all but seven flights. For only seven flights, it is not recommended to develop a low leakage, nonventing EVA system and EVA for these seven flights must be performed with the shields closed.

5.8.2 Particle Deposition Significance

The significance of particle deposition is that sensor shields must be closed during nearby EVA. Shields must also remain closed for approximately three minutes for particles to clear after completion of EVA, and portable shielding (or equivalent) may be required to perform EVA service near an open shield sensor.

5.8.3 Significance of Scattering, Absorbtion and Emission By Particles

Measurements through the particle wake may be affected from 1 to 35 hours on 81 flights. However, the delay required for measurements to be taken through the particle wake has already been accounted for in the 73 flights required to launch and service the astronomy free flyers. The RAM study indicates present planning calls for leaving the shields of the free flyers closed for 48 hours after departure of the Shuttle from the vicinity of the free flyer. Therefore, the 1 to 35 hour delay for particles to clear affects only Shuttle sortie flights, and then, only if measurements are to be taken through the particle wake.

The expected time for particles and ice crystals to clear is shown in Figure A5-7 as a function of altitude and particle size. The RAM Study Contamination Analysis is the source of the calculations performed.

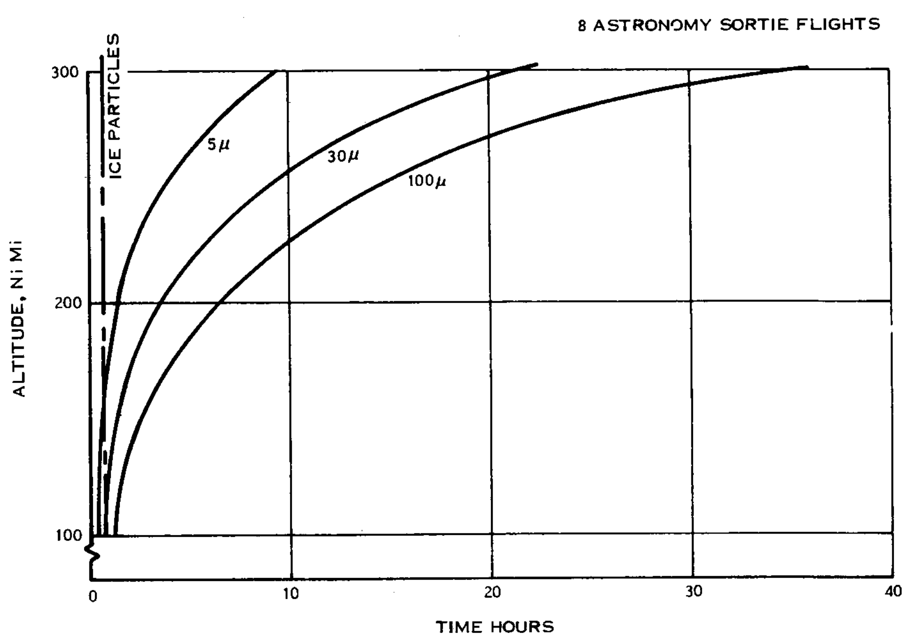

FIGURE A5—7. TIME TO CLEAR PARTICLES

5.9 Conclusions

a) Eighty-five (85) of the total of 677 NASA and DOD Shuttle flights were estimated to be transporting contamination sensitive payloads. On seventy-eight (78) of these flights, the payloads are sensitive to particulate deposition only. On seventy-three (73) of these seventy= eight (78) flights, the contamination sensitive payloads are astronomy free flyers. On these payloads, the experiment package utilizes contamination shields which normally remain closed whenever the Shuttle is in the immediate area and are not opened until forty-eight (48) hours after the Shuttle leaves the area. Since it takes from one (1) to thirty-five (35) hours for particulate to clear before an experiment can be activated, contamination will not normally pose a problem for these payloads. On the remaining five (5) flights which carry payloads that are sensitive to particulate contamination only, special precautions are required. The instrumentation shields must be closed during EVA on these flights and a waiting period of one (1) to thirty-five (35) hours are required before the experiment can be activated.

b) On the remaining seven flights, three (3) are sensitive to particulate contamination and all seven (7) are sensitive to water vapor contamination. The payload instrumentation shields must be closed during EVA on these flights to avoid payload contamination. Although a PLSS water umbilical could be used to eliminate the major source of water vapor, the water vapor contained in the EVA suit leakage and/or orbiter leakage is enouth to contaminate these payloads.

c) A general conclusion of this effort is if the payload instrumentation shields are closed during EVA operations which are near contamination sensitive payloads, an Apollo-type EVA system using water as a thermal control subsystem evaporant and having a suit gaseous leakage rate of 100 scc/min. is a useable system for performing Shuttle missions.

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APPENDIX B

SUIT PRESSURE LEVEL DETERMINATION

WEIGHT AND VOLUME ANALYSIS

1.0 GENERAL

This Appendix provides additional weight and volume data to support the results and conclusions of Section 6.0 of Volume I. The effect of suit pressure on the EVA system weight and volume is first established and then the total effect on the Orbiter weight and volume for support of multiple EVA's is defined.

2.0 SUIT PRESSURE LEVEL EFFECT ON EVA SYSTEM WEIGHT AND VOLUME

The weight and volume of the following items of the EVA system are affected by suit pressure level:

a) Pressure Suit
b) PLSS
c) ELSS
d) Pre-Breathing Equipment

Although some of the weight and volume penalties are not significant, they will be considered as part of this evaluation.

2.1 Effect of Suit Pressure Level on the Pressure Suit

Section 6.0 of Volume I points out that the suit weight and volume is influenced primarily by the type of suit used (hard, soft, or combination) rather than the suit operating pressure. For the purpose of evaluating weight and volume impacts on the Orbiter, a conservative approach was taken which penalizes the suit weight at the higher pressure levels as shown in Figure B2-1.

Since the suit stowage volume is unaffected by pressure level, a volume of 10,400 cubic inches was used for this evaluation.

2.1 Effect of Suit Pressure Level on the Pressure Suit - Continued

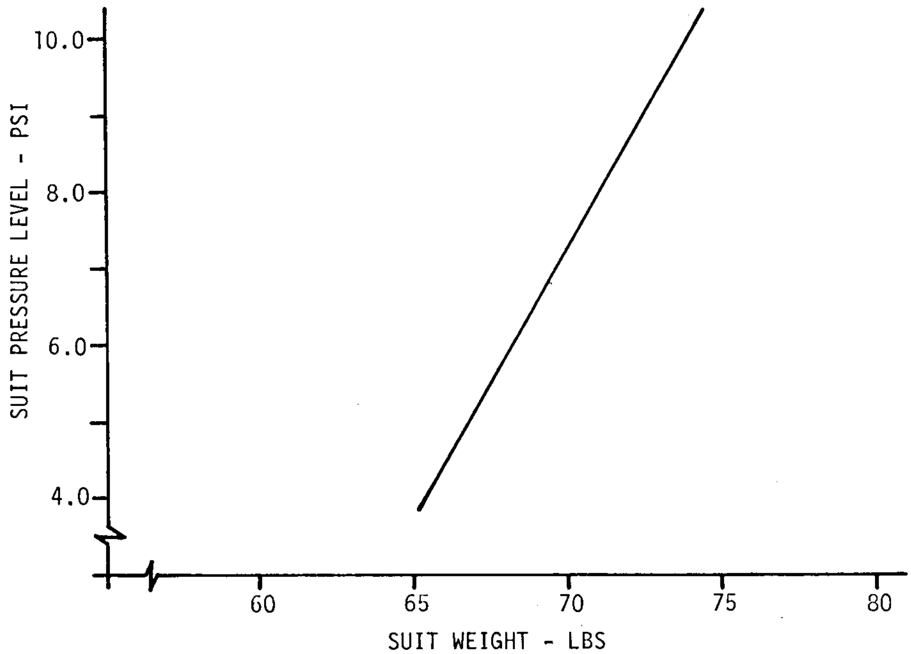

FIGURE B2-1. SUIT WEIGHT VS PRESSURE

2.2 Effect of Suit Pressure Level on PLSS

The weight and volumes of four (4) types of Primary Life Support Systems were established for each of the candidate suit pressure levels. The requirements specified and the types of systems evaluated are specified in detail in Section 6.0 of Volume I and will not be repeated here. The weight and volumes of the self-contained and the umbilical systems are shown in Figure B2-2 which includes only those PLSS functions affected by suit pressure level.

A large percentage of the weight and volume of the umbilical system is comprised of the basic umbilical since each type of system requires different oxygen flow rates and supply pressures, the umbilical weight varies as a function of suit operating pressure and the type of PLSS in use.

2.2 Effect of Suit Pressure Level on PLSS - Continued

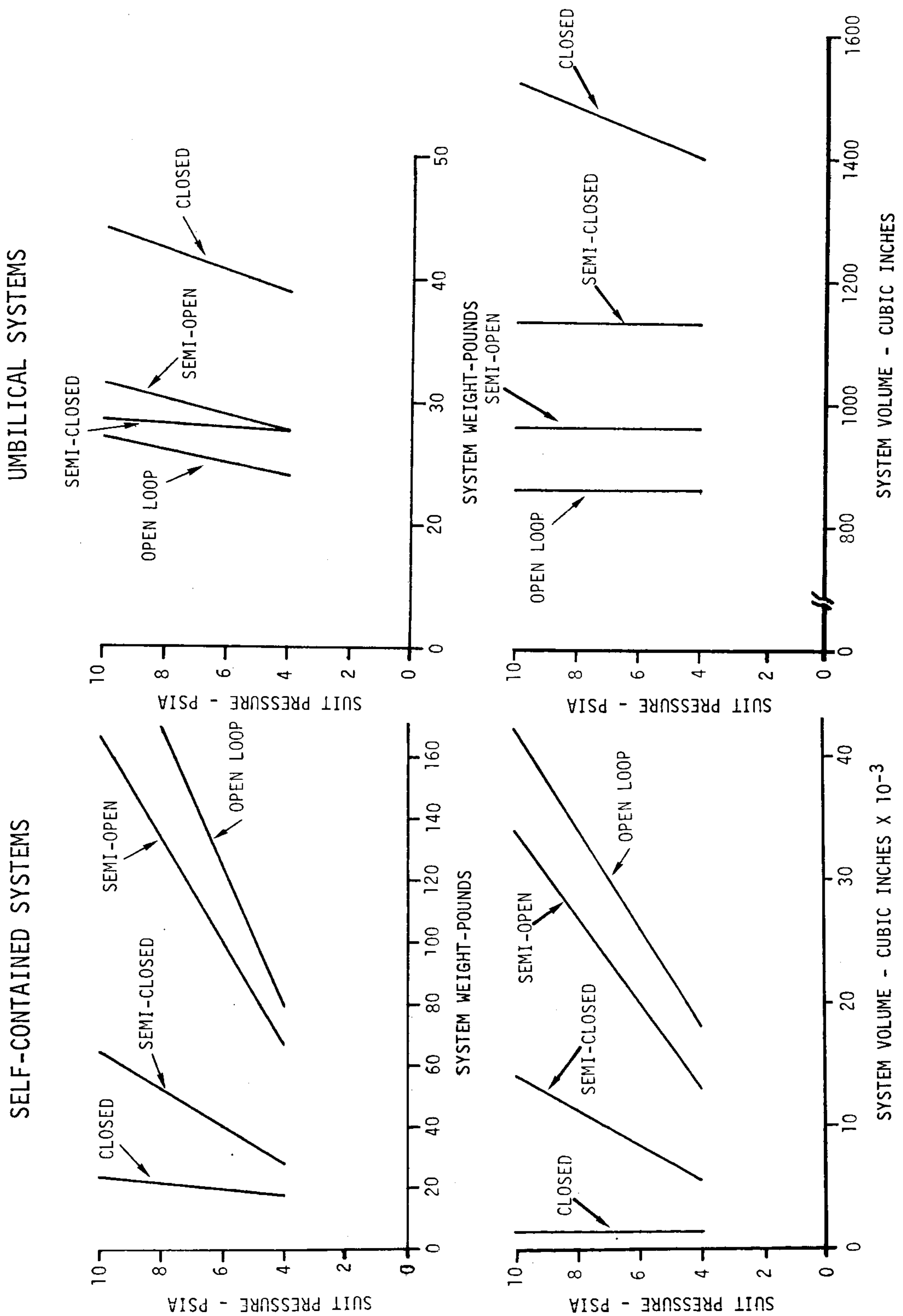

FIGURE B2-2. SUIT PRESSURE VS PLSS WEIGHT AND VOLUME

2.2 Effect of Suit Pressure Level on PLSS - Continued

Figure B2-3 shows the result of an umbilical sizing effort which establishes the required umbilical weights.

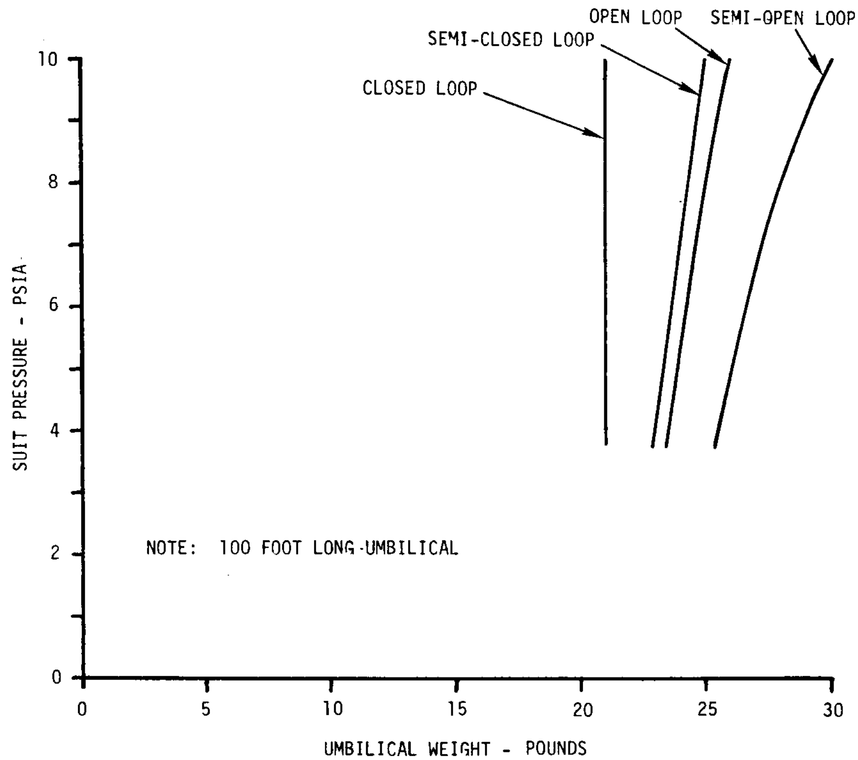

FIGURE B2-3. PRIMARY LIFE SUPPORT SYSTEM UMBILICAL WEIGHTS

The umbilical stowage volume is the same for all pressure levels and for all system types. For this evaluation, an umbilical stowage volume of 12,100 cubic inches was estimated.

From review of Figure B2-2, it can be seen that only one of the self-contained systems is competitive from a weight and volume stand point. All of these system, except for the closed loop system, are too large and heavy for use by an EV crewmen. Of the umbilical system all weights and volumes are competitive. However, the closed loop umbilical system is slightly larger and heavier than the self-contained closed loop system

2.2 Effect of Suit Pressure Level on PLSS - Continued

and also has the disadvantage of umbilical management. Therefore, the closed loop umbilical system is also eliminated from further evaluation.

As a result of this review, the following PLSS concepts require further evaluation to establish the vehicle penalties.

a) Self-Contained: Closed Loop
b) Umbilical: Open Loop
c) Umbilical: Semi-Open Loop
d) Umbilical: Semi-Closed Loop

Each of the above systems require consumables for EVA operation. Table B2-1 identifies the consumable types and quantities which are to be supplied by the vehicle.

SUIT PRESSURE LEVEL	SYSTEM TYPE	OXYGEN REQUIRED		LIOH CARTRIDGE		BATTERY	
		WT-LBS	VOL-IN³ (LOX)	WT-LBS	VOL-IN³	WT-LBS	VOL-IN³
4.0 PSI	SELF-CONTAINED: CLOSED	0.70	17.1	2.2	200	2.4	60
	UMBILICAL: OPEN	22.0	537.	-	-	-	-
	UMBILICAL: SEMI-OPEN	17.4	425.	-	-	-	-
	UMBILICAL: SEMI-CLOSED	6.4	156.	1.8	165	-	-
6.0 PSI	SELF-CONTAINED: CLOSED	0.7	17.1	2.2	200	2.6	65
	UMBILICAL: OPEN	33.0	815.	-	-	-	-
	UMBILICAL: SEMI-OPEN	26.0	720.	-	-	-	-
	UMBILICAL: SEMI-CLOSED	9.4	229.	1.8	165	-	-
8.0 PSI	SELF-CONTAINED: CLOSED	0.7	17.1	2.2	200	3.2	80
	UMBILICAL: OPEN	44.0	1075.	-	-	-	-
	UMBILICAL: SEMI-OPEN	35.0	854.	-	-	-	-
	UMBILICAL: SEMI-CLOSED	12.6	308.	1.8	165	-	-
10.0 PSI	SELF-CONTAINED: CLOSED	0.7	17.1	2.2	200	4.0	100
	UMBILICAL: OPEN	55.0	1320.	-	-	-	-
	UMBILICAL: SEMI-OPEN	43.0	1050.	-	-	-	-
	UMBILICAL: SEMI-CLOSED	15.8	386.	1.8	165	-	-

TABLE B2-1. CANDIDATE PLSS CONSUMABLES REQUIREMENTS

2.2 Effect of Suit Pressure Level on PLSS - Continued

Penalties imposed on the vehicle for providing these consumables will be assessed in Section 3.0 of this Appendix. Each of the above systems except for the open loop system require an expendable water supply for humidity control and equipment heat loads. Since water can be obtained from the Orbiter at no penalty, the water quantities required is not specified. However, the water weight, tankage and that portion of the thermal control system required for humidity control and equipment loads is included in the basic PLSS weights. For this review, the weight of a sublimator was included for all systems requiring an active cooling capability.

2.3 Effect of Suit Pressure Level on ELSS

Section 6.0 of Volume I discusses the ELSS requirements and concept in detail and concludes that the Open Loop ELSS is the most competitive type system primarily due to its simplicity. It is also pointed out that the Open Loop ELSS weights and volumes are representative of any ELSS type. Figure B2-4 identifies the Open Loop ELSS weights and volumes.

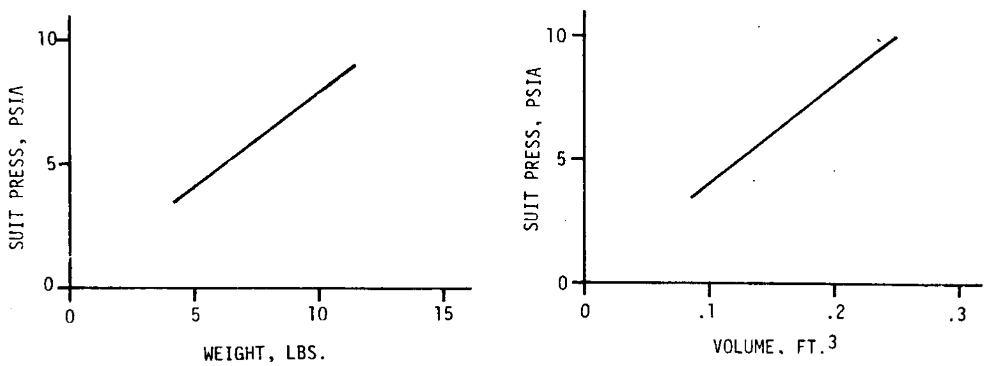

FIGURE B2–4. OPEN LOOP ELSS WEIGHT AND VOLUME

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2.4 Effect of Suit Pressure Level on Pre-Breathing Equipment

After a thorough review of candidate pre-breathing equipment concept (Reference Section 6.0 of Volume I) it was concluded that a semi-closed loop pre-breather utilizing CO_2 scrubbing is the logical concept selection if pre-breathing is required. The weights and volumes of this type system are shown in Figure B2-5 as a function of suit pressure level.

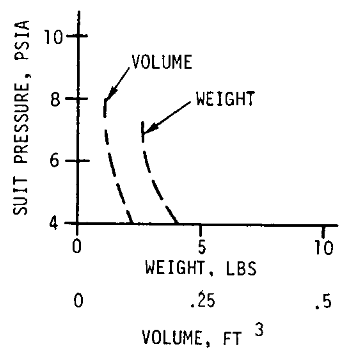

FIGURE B2-5. WEIGHT AND VOLUME IMPACT OF PREBREATHING

The pre-breathing equipment, like the PLSS, also utilizes consumables to be carried by the Orbiter. The amounts of Oxygen and LiOH to be used for a single pre-breathing period are defined in Table B2-2 as a function of suit pressure level.

SUIT PRESSURE LEVEL	OXYGEN		LIOH CARTRIDGE	
	WT-LBS	VOL-IN^3 (LOX)	WT-LBS	VOL-IN^3
4.0 PSIA	0.60	14.7	0.65	59.0
5.0 PSIA	0.45	10.9	0.35	45.0
6.0 PSIA	0.38	9.3	0.20	32.0
7.0 PSIA	0.35	8.5	0.10	20.0

TABLE B2-2. PREBREATHING EQUIPMENT CONSUMABLES REQUIREMENTS

These consumables will be utilized to evaluate total vehicle penalties for multiple EVA support.

2.5 Effect of Suit Pressure on Suit Purging

As part of the suit donning sequence following pre-breathing, it is necessary to remove any nitrogen from the suit in order to maintain the crewman denitrogenization status. Therefore, equipment and oxygen must be available for suit purging to reduce the N_2 concentration to less than 3%. Analysis shows that 3.15 lbs (77 cu. in.) of supercritical stored oxygen must be purged through the suit to satisfy this requirement. For the purpose of this review, the weights and volumes of the purge control equipment is omitted and only the oxygen penalties are considered. This assumption slightly favors the lower suit pressure levels.

3.0 EFFECT OF SUIT PRESSURE LEVEL ON THE ORBITER

The selection of suit pressure level must include the vehicle launch weights and volumes imposed on the vehicle by the various candidate suit pressures. These launch weights and volumes are established by the summation of penalties established in paragraph 2.0 of this Appendix including the EVA equipment and the vehicle supplied consumables.

Tables B3-1 and B3-2 summarize the launch weights and volumes for candidate pressures of 4, 6, 8, and 10 psia. The results of these tables are plotted in Figures B3-1 and B3-2, and discussed in Section 6.0 of Volume I.

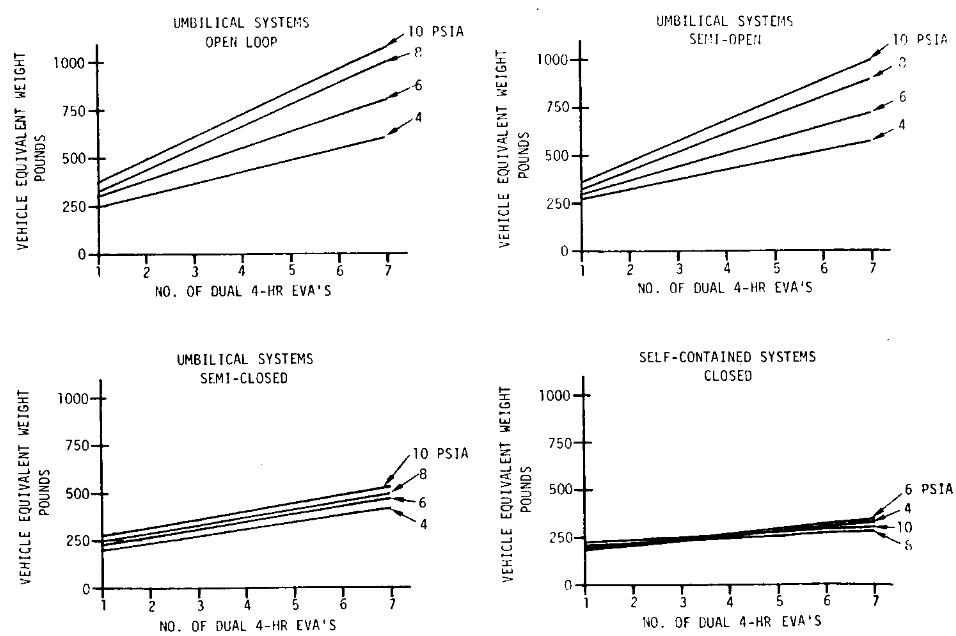

FIGURE B3-1. SUIT PRESSURE IMPACT ON ORBITER WEIGHT

3.0 EFFECT OF SUIT PRESSURE LEVEL ON THE ORBITER (CONTINUED)

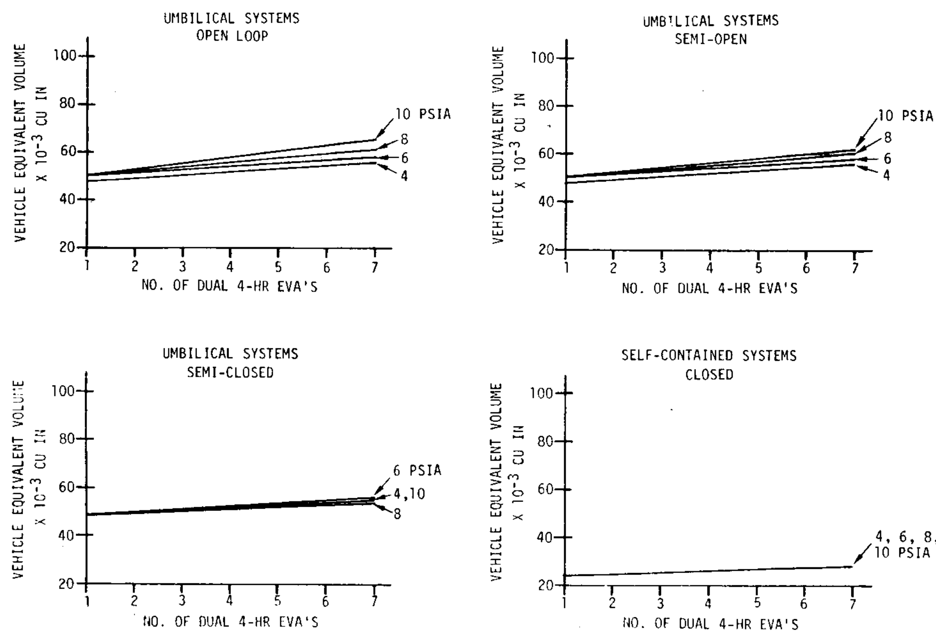

FIGURE B3-2. SUIT PRESSURE IMPACT ON ORBITER VOLUME

3.0 EFFECT OF SUIT PRESSURE LEVEL ON THE ORBITER - CONTINUED

Suit Press.	Basic EVA Equipment Wt - Lbs: Suit	ELSS	P/B	PLSS Type	PLSS Wt.	Total	Vehicle Oxygen For 1st EVA - Lbs: P/B	Purge	EVA USE	Total	With Tank	Launch Weight One Dual EVA	Vehicle Support For Subsequent EVA's - Lbs/Man/EVA: OXYGEN P/B	OXYGEN Purge	OXYGEN EVA USE	OXYGEN Total	OXYGEN With Tank	LiOH P/B	LiOH PLSS	LiOH Total	PLSS Batt.	Total Per Man	ΔFor 2 Dual EVA's	Δ For 7 Dual EVA's	Launch Weight For 7 Dual EVA's
4.0 Psia	65.3	5.5	4.0	Self-Cont: Closed	19.0	93.8	0.60	3.15	-	3.75	4.7	197.0	0.60	3.15	0.70	4.45	5.6	0.65	2.2	2.85	2.4	8.69	17.4	104.4	301.4
				Umb: Open Loop	24.2	99.0	0.60	3.15	22.0	25.75	32.2	262.4	0.60	3.15	22.0	25.75	32.2	0.65	-	0.65	-	32.85	65.7	394.2	656.6
				Umb: Semi-Open	27.5	102.3	0.60	3.15	17.4	21.15	26.4	257.4	0.60	3.15	17.4	21.15	26.4	0.65	-	0.65	-	27.05	54.1	324.6	582.0
				Umb: Semi-Closed	27.5	102.3	0.60	3.15	6.4	10.15	12.7	230.0	0.60	3.15	6.4	10.15	12.7	0.65	1.8	2.45	-	15.15	30.3	181.8	411.8
6.0 Psia	68.1	7.5	2.9	Self-Cont: Closed	20.5	99.0	0.38	3.15	-	3.53	4.4	206.8	0.38	3.15	0.70	4.23	5.3	0.20	2.2	2.40	2.6	10.30	20.6	123.6	330.4
				Umb: Open Loop	25.1	103.6	0.38	3.15	33.0	36.53	45.7	298.6	0.38	3.15	33.0	36.53	45.7	0.20	-	0.20	-	45.9	91.8	550.8	849.4
				Umb: Semi-Open	28.7	107.2	0.38	3.15	26.0	29.53	36.9	288.2	0.38	3.15	26.0	29.53	36.9	0.20	-	0.20	-	37.1	74.2	445.2	733.4
				Umb: Semi-Closed	27.5	106.0	0.38	3.15	9.4	12.93	16.2	244.4	0.38	3.15	9.4	12.93	16.2	0.20	1.8	2.0	-	18.2	36.4	218.4	462.8
8.0 Psia	71.0	10.3		Self-Cont: Closed	22.0	103.3	-	-	-	-		206.6	-	-	0.70	0.70	0.9	-	2.2	2.2	3.2	6.3	12.6	75.6	282.2
				Umb: Open Loop	26.0	107.3	-	-	44.0	44.0	55	324.6	-	-	44.0	44.0	55	-	-	-	-	55.0	110	660	984.6
				Umb: Semi-Open	30.1	111.4	-	-	35.0	35.0	43.7	310.2	-	-	35.0	35.0	43.7	-	-	-	-	43.7	87.4	524.4	834.6
				Umb: Semi-Closed	28.0	109.3	-	-	12.6	12.6	15.7	250	-	-	12.6	12.6	15.7	-	1.8	1.8	-	17.5	35.0	210	460.0
10.0 Psia	73.8	13.0		Self-Cont: Closed	24.0	110.8	-	-	-	-		221.6	-	-	0.70	0.70	0.9	-	2.2	2.2	4.0	7.1	14.2	85.2	306.8
				Umb: Open Loop	27.1	113.9	-	-	55.0	55.0	68.7	365.2	-	-	55.0	55.0	68.7	-	-	-	-	68.7	137.4	822	1187.2
				Umb: Semi-Open	32.0	118.8	-	-	43.0	43.0	53.7	345.0	-	-	43.0	43.0	53.7	-	-	-	-	53.7	107.4	642	987.0
				Umb: Semi-Closed	29.0	115.8	-	-	15.8	15.8	19.7	271.0	-	-	15.8	15.8	19.7	-	1.8	1.8	-	21.5	43.0	258	529.0

P/B = PREBREATHE

TABLE B3-1. SUMMATION OF LAUNCH WEIGHTS

Suit Press.	Basic EVA Equipment Vol-Cu. In.: Suit	ELSS	P/B	PLSS P/B Type	PLSS Vol.	Total	Vehicle Support For 1st EVA-Cu. In.: O_2 P/B	O_2 Purge	O_2 EVA Use	Umb. Stowage	Total	Launch Volume For One Dual EVA	Vehicle Support For Subsequent EVA's - Cu. In.: Oxygen P/B	Oxygen Purge	Oxygen EVA Use	Oxygen Total	LiOH P/B	LiOH PLSS	LiOH Total	PLSS Batt	Total Per Man	ΔFor 2nd Dual EVA	ΔFor 7 Dual EVA	Launch Volume For 7 Dual EVA
4.0 Psia	10,400	173	190	Self Cont: Closed	1127	11,890	15	77	-	-	92	23,964	15	77	17	109	59	200	259	60	428	856	5,136	29,103
				Umb: Open Loop	865	11,628	15	77	537	12,100	12,729	48,714	15	77	537	629	59	-	59	-	688	1396	8,256	56,970
				Umb: Semi-Open	965	11,728	15	77	425	12,100	12,617	48,690	15	77	425	517	59	-	59	-	576	1152	6,912	49,842
				Umb: Semi-Closed	1130	11,893	15	77	156	12,100	12,348	48,482	15	77	156	248	59	165	224	-	472	944	5,664	54,146
6.0 Psia	10,400	260	120	Self-Cont: Closed	1162	11,942	10	77	-	-	87	24,058	10	77	17	104	32	200	232	65	401	802	4,812	28,870
				Umb: Open Loop	865	11,645	10	77	815	12,100	13,002	49,294	10	77	815	902	32	-	32	-	934	1868	11,208	60,502
				Umb: Semi-Open	965	11,745	10	77	720	12,100	12,907	49,304	10	77	720	807	32	-	32	-	839	1678	10,068	59,372
				Umb: Semi-Closed	1130	11,910	10	77	317	12,100	12,504	48,828	10	77	317	404	32	165	197	-	601	1202	7,212	56,040
8.0 Psia	10,400	346	-	Self-Cont: Closed	1197	11,943	-	-	-	-	-	23,886	-	-	17	17	-	200	200	80	297	594	3,564	27,450
				Umb: Open Loop	865	11,611	-	-	1075	12,100	13,175	49,572	-	-	1075	1075	-	-	-	-	1075	2150	12,900	62,472
				Umb: Semi-Open	965	11,711	-	-	854	12,100	12,954	49,330	-	-	854	854	-	-	-	-	854	1708	10,248	59,578
				Umb: Semi-Closed	1130	11,876	-	-	308	12,100	14,408	48,568	-	-	308	308	-	165	165	-	473	946	5,676	54,244
10.0 Psia	10,400	432	-	Self-Cont: Closed	1239	12,071	-	-	-	-	-	24,142	-	-	17	17	-	200	200	100	317	634	3,804	27,946
				Umb: Open Loop	865	11,697	-	-	1320	12,100	13,420	50,234	-	-	1320	1320	-	-	-	-	1320	2640	15,840	66,074
				Umb: Semi-Open	965	11,797	-	-	1050	12,100	13,150	49,894	-	-	1050	1050	-	-	-	-	1050	2100	12,600	62,494
				Umb: Semi-Closed	1130	11,962	-	-	386	12,100	12,486	48,896	-	-	386	386	-	165	165	-	551	1102	6,612	55,508

P/B = PREBREATHE

TABLE B3-2. SUMMATION OF LAUNCH VOLUMES

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APPENDIX C

PRIMARY LIFE SUPPORT SYSTEM

SUBSYSTEMS STUDIES

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1.0 OXYGEN SUPPLY SUBSYSTEM

The oxygen supply subsystem of a closed loop PLSS maintains suit pressure and provides oxygen make-up for crewman metabolic consumption and suit and PLSS external leakage. Table C1-1 lists the specific requirements for this subsystem.

Suit Pressure	8.2 ± 0.2 psi
Oxygen Storage	0.77 lbs useable O_2
Oxygen Delivery Metabolic Consumption Leakage	 0.175 lbs/hr 0.017 lbs/hr

TABLE C1-1. OXYGEN SUPPLY SUBSYSTEM REQUIREMENTS

The study considered fourteen candidate oxygen supply concepts, in four basic categories, which are listed in Table C1-2.

I. Oxygen Storage 1. Gaseous (900-6000 psi) 2. Supercritical Utilizing Thermal Pressurization 3. Subcritical Utilizing Thermal Pressurization 4. Subcritical Utilizing Positive Expulsion 5. Solid
II. Solid Decomposition 6. Superoxides (KO_2) 7. Peroxides (Li_2O_2) 8. Ozonides 9. Sodium Chlorate Candles ($NaClO_3$) 10. Lithium Perchlorate Candles ($LiClO_4$)
III. Liquid Decomposition 11. Hydrogen Peroxide 12. Reactant Storage (N_2H_4/N_2O_4) 13. Reactant Storage (N_2H_4/N_2O_4)
IV. Electrolysis 14. Water Electrolysis

TABLE C1-2. OXYGEN SUPPLY SUBSYSTEM CONCEPTS

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1.1 Initial Evaluation

The purpose of this section is to present an initial evaluation of all of the oxygen supply concepts listed in Table C1-2 in order to eliminate those candidates which do not merit serious consideration in the detailed evaluation (Reference Section 1.2). This preliminary analysis is based on experience gained through previous spacecraft and personal protection equipment studies.

Figure C1-1 presents a relative weight analysis for each concept and indicates that gaseous and liquid oxygen storage are the lightest candidates followed by solid chemical decomposition and liquid decomposition of hydrogen peroxide.

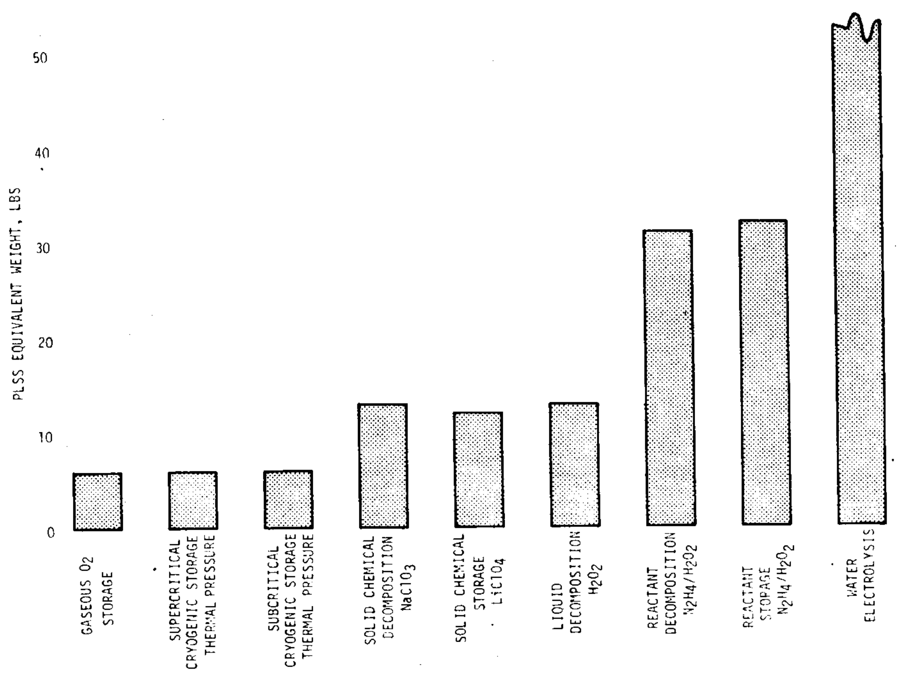

FIGURE C1-1. OXYGEN SUBSYSTEM RELATIVE WEIGHT ANALYSIS

Reactant storage and water electrolysis are eliminated at this juncture due to the significant PLSS weight penalty indicated in the above figure.

1.1 Initial Evaluation - Continued

The following paragraphs present the results of the initial evaluation of those concepts which are competitive on a weight basis.

1.1.1 Gaseous & Liquid Oxygen Storage

Gaseous oxygen storage is the simplest candidate and the only one which has the capability of rapidly providing oxygen in the event of an emergency decompression of the suit. Within this category, both the gaseous and cryogenic liquid storage concepts are very similar in weight. Since the PLSS will be stored in the cabin area, an active cooling system is required to maintain the liquid oxygen state without boiling off some of the contained oxygen. If boil-off is allowed, additional oxygen must be stored and the boil-off to the cabin could affect cabin oxygen concentrations. These operational penalties coupled with the added complexity of liquid oxygen storage warrants warrants its elimination from further review.

1.1.2 Solid Chemical Decomposition

Within this category, the superoxides, peroxides and ozonides are not evaluated as oxygen supply concepts, but rather are studied in conjunction with their CO_2 control capability (Reference Section 2.0). Thus, only sodium chlorate and lithium perchlorate candles are evaluated for oxygen supply in the solid decomposition category. However, the development status of the lithium perchlorate candles relative to the sodium chlorate candles eliminates them as a competitive concept.

1.1.3 Liquid Decomposition

Within this category, reactant storage has previously been eliminated based on the weight impact and thus only hydrogen peroxide remains. This concept, however, also forms water vapor as a result of the decomposition and is eliminated since the removal of this water vapor results in an excessive penalty to the humidity control subsystem. Secondly, the H_2O_2 tends to be unstable and requires special handling during ground and flight operation.

1.1.4 Summary

Based on this initial evaluation, the oxygen supply concepts listed in Table C1-3 are selected for detailed evaluation.

GASEOUS O_2 STORAGE
SODIUM CHLORATE CANDLES

TABLE C1–3. OXYGEN SUPPLY CONCEPTS

1.2 Detailed Evaluation

The purpose of this section is to select the best approach for the Shuttle PLSS Oxygen Supply Subsystem for use in a closed loop system. This is accomplished by presenting details of each of the candidates previously listed in Table C1-3, followed by a summary evaluation and selection.

1.2.1 Gaseous O_2 Supply Concepts

The competitiveness of a gaseous O_2 supply subsystem depends on the operating pressure at which oxygen is stored. The optimum oxygen storage pressure imposes the lowest weight, volume, cost and operational penalties to the PLSS and to the Orbiter. In this section, various candidate pressure levels are reviewed and the optimum pressure level is selected.

The study, considers pressure levels in the range of 900 to 6000 psia. The pressure level of 900 psia was considered the minimum oxygen storage pressure since it is available on the current baseline Orbiter and because lower storage pressures require a significantly larger storage vessel as indicated by Figure C1-2, which reflects the use of spherical bottles.

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1.2.1 Gaseous O_2 Supply Concepts (Continued)

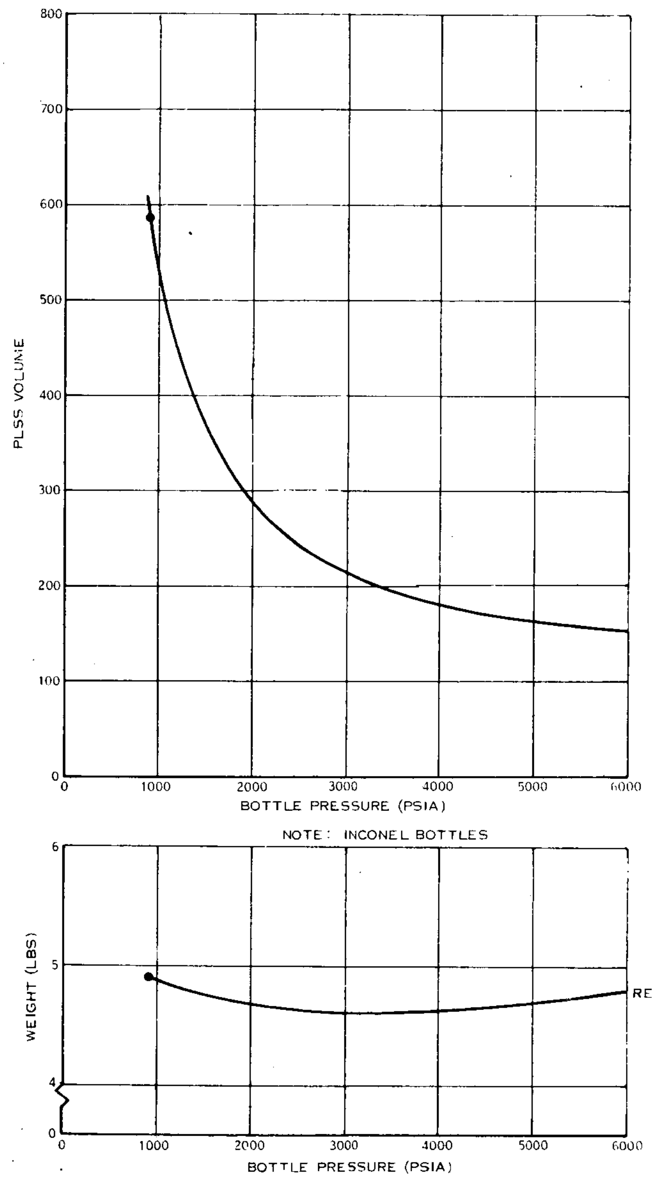

FIGURE C1—2. OXYGEN SUBSYSTEM VOLUME AND WEIGHT VS BOTTLE PRESSURE

1.2.1 Gaseous O_2 Supply Concepts (Continued)

The maximum pressure considered is 6000 psia because system weights for pressures above this level are heavier (in terms of tank weight per pound of O_2) with negligible volume savings, as also indicated by Figure C1-2.

For oxygen refurbishment between EVA's, the following concepts were considered:

- Oxygen Recharge
- Replacement of Precharged Oxygen Bottles
- Replacement of Precharged Oxygen Supply Subsystems

1.2.1.1 Oxygen Recharge

The oxygen recharge concept, shown schematically in Figure C1-3, is similar to the method used on Apollo for EMU PLSS oxygen recharge by the lunar module.

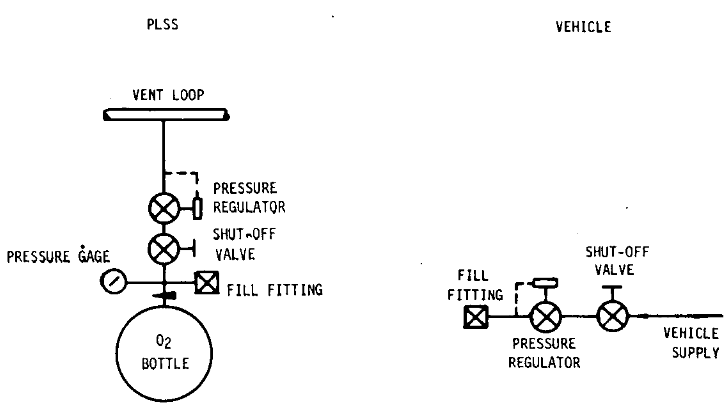

FIGURE C1–3. OXYGEN RECHARGE SCHEMATIC

The PLSS system supplies the vent loop from a storage bottle through a shut-off valve and pressure regulator. The vehicle recharge system receives oxygen from the vehicle supply source and passes it through a shut-off valve and pressure

1.2.1.1 Oxygen Recharge (Continued)

regulator to a fill fitting which mates with the fill fitting on the PLSS. The operating pressure levels of this concept are limited by the operating pressures available from the baseline Orbiter which are 900 psia and 3000 psia. The 900 psia pressure level is supplied from super-critical oxygen storage vessels which also provide oxygen for cabin pressure control and for fuel cell operation. The current Orbiter baseline provides for PLSS recharge from this source. The 3000 psia pressure level is available from two gaseous oxygen storage vessels containing twenty-five (25) pounds of O_2 each. The current baseline use of this supply is:

- Airlock Repressurizations
- Emergency Cabin Repressurization
- Contingency Oxygen to Support a Crew of Four (4) Men for 96 Hours

Use of this oxygen source for PLSS recharge can be accomplished by increasing the Orbiter O_2 storage vessel volume to contain the O_2 required for the PLSS recharge while maintaining the same storage pressure of 3000 psia. Analysis shows that after removal of all PLSS recharge oxygen, the re-sized storage vessels are at a pressure of 2600 psia and contain fifty (50) pounds of oxygen for the uses discussed above. This approach establishes the second recharge concept of recharging the PLSS to 2600 psia from the Orbiter 3000 psia gaseous O_2 supply. It is recognized that use of the 3000 psia supply oxygen for airlock pressurizations reduces the oxygen supply pressure such that the 2600 psia recharge pressure cannot be obtained. For the purpose of this evaluation, it is assumed that the airlock pressurization is accomplished by some other method such as pump down or from the vehicle supercritical oxygen source. If it is found that this concept is favorable over the other concepts, the weight, volumes, and operational penalties of this assumption will be fully assessed prior to concept selection.

Since it is not possible to charge the PLSS to 3000 psia from a limited volume of 3000 psia gaseous O_2 source, a third concept is considered which consists of a 6000 psia gaseous oxygen storage reservoir carried on each flight for the sole purpose of charging the PLSS O_2 subsystem to 3000 psia.

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1.2.1.1 Oxygen Recharge (Continued)

Table C1-4 is a comparison of weight and volume penalties imposed on the PLSS and the vehicle by each of the three candidate recharge concepts.

CONCEPT	PLSS		VEHICLE	
	WT-LBS	VOL-IN^3	WT-LBS	VOL-IN^3
900 PSIA RECHARGE	4.85	580	19.0	1400
2600 PSIA RECHARGE FROM 3000 PSIA SOURCE	4.65	240	32.0	1600
3000 PSIA RECHARGE FROM 6000 PSIA SOURCE	4.60	215	54.0	1600

TABLE C1-4. OXYGEN RECHARGE CONCEPTS COMPARISON

This table reflects the PLSS weight and volume penalties defined by Figure C1-2. The vehicle penalties are based on a mission requiring five (5) dual EVA's where oxygen for the first EVA is provided by a pre-flight charge. Therefore, the vehicle provides 32 man-hours of EVA support by providing oxygen for four (4) dual 4-hour EVA's. The vehicle weights and volumes also include the PLSS O_2 system weights and volumes since the PLSS is stowed on board the spacecraft.

At this juncture, the concept for PLSS recharge to 3000 psia from a 6000 psia source is eliminated because of its high vehicle weight penalty with no appreciable PLSS weight or volume savings over the other concepts. The remaining recharge concepts will be compared with the replaceable concepts for final gaseous O_2 supply subsystems evaluation.

1.2.1.2 Replaceable Precharged O_2 Bottles and Subsystems

The primary advantage of replacing O_2 bottles or subsystems is to utilize pressures beyond those available by vehicle oxygen recharge to obtain further PLSS volume savings. Therefore, the replaceable bottles or subsystems are considered for oxygen storage pressures in the range of 3000 to 6000 psia.

The installation of a high pressure (3000 to 6000 psia) precharged O_2 bottle involves the pneumatic connection of a high pressure fitting. Since the force-to-connect this fitting is proportional to the operating pressure, the force may be beyond the physical capability of the crewman to use a quick disconnect fitting of current technology. Solutions of this potential problem include: development of a high pressure quick disconnect; use of threaded fittings; and incorporation of isolation and bleed valves to reduce the pressure while the connection is made. For concept identification and evaluation, it is assumed that an acceptable quick disconnect is available.

Another option is to eliminate the need for inflight connection of a high pressure fitting by replacing the entire O_2 supply subsystem as shown schematically in Figure C1-4.

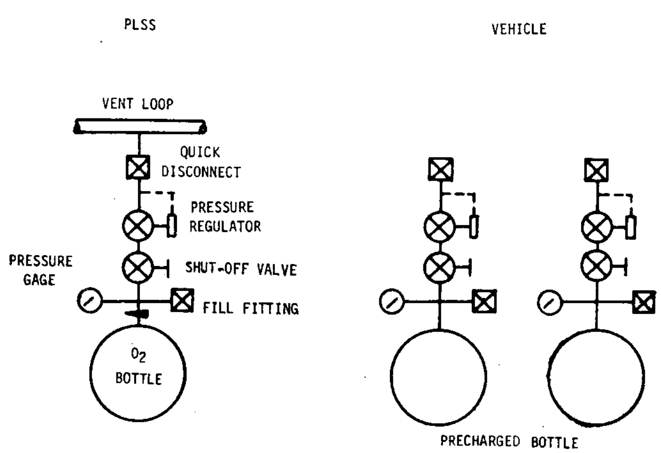

FIGURE C1–4. REPLACEABLE OXYGEN SUPPLY SUBSYSTEM SCHEMATIC

1.2.1.2 Replaceable Precharged O_2 Bottles and Subsystems (Continued)

In this concept, the connections/disconnections are made downstream of the pressure regulator. An electrical connection will also be required for any instrumentation associated with the O_2 pressure transducer.

The difference in PLSS weights and volume for replaceable O_2 bottles versus replaceable O_2 supply subsystems is negligible. However, the replaceable O_2 subsystem concept imposes additional weight and volume penalties on the vehicle, as shown by Figure C1-5, which is primarily due to the additional quantities of regulators, gages and shutoff valves which must be stowed by the vehicle.

Although the weight and volume penalties for the replaceable O_2 subsystem concept are significant, the concept cannot be eliminated without assurance that high pressure bottles can be replaced through the use of a quick disconnect. Therefore, both concepts warrant further evaluation along with the O_2 rechargeable concepts of Paragraph 1.2.1.1.

1.2.1.2 Replaceable Precharged O_2 Bottles and Subsystems (Continued)

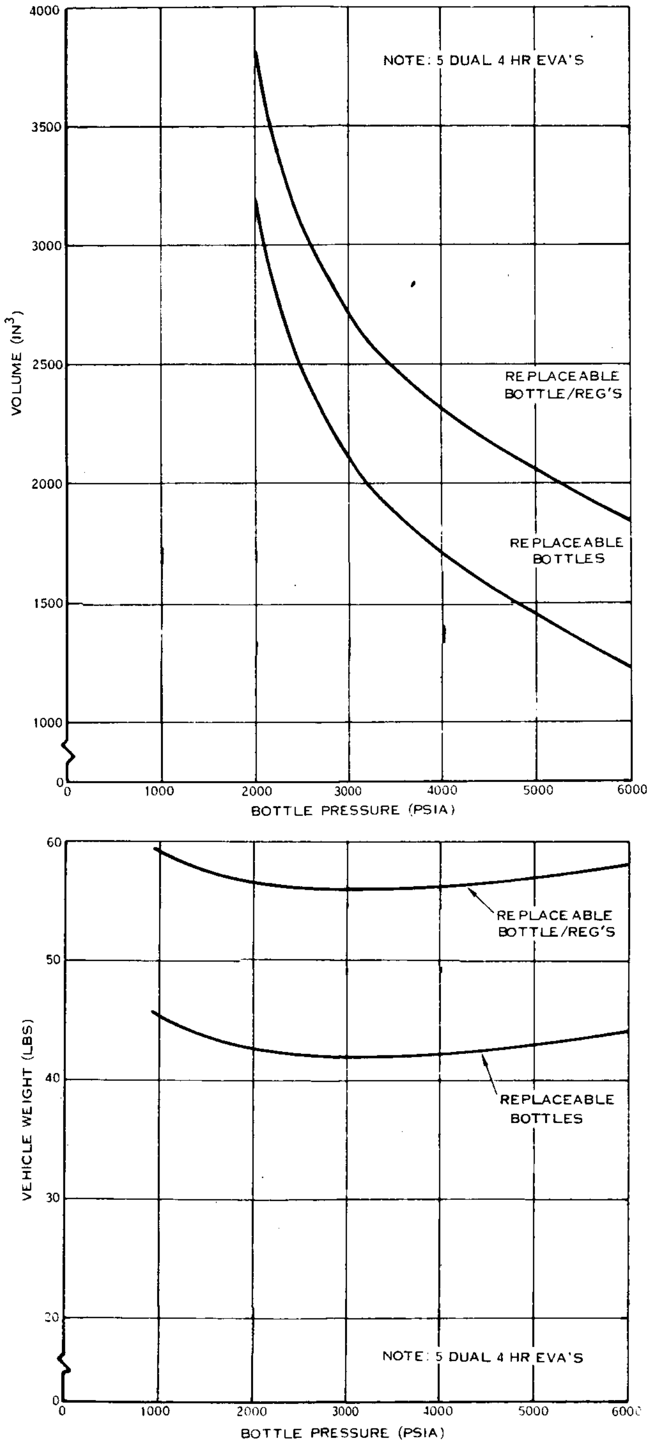

FIGURE C1–5. SHUTTLE WEIGHT AND VOLUME-REPLACEABLE CONCEPTS

1.2.1.3 Gaseous O_2 Supply Concept Evaluation

The gaseous O_2 supply concepts to be evaluated are:

- 900 psia Recharge from Vehicle Super-Critical Oxygen Storage (Baseline)
- 2600 psia Recharge from the Vehicle 3000 psia Baseous Oxygen Storage (Modified)
- Replaceable PLSS O_2 Bottles (3000 to 6000 psia)
- Replaceable PLSS O_2 Subsystems (3000 to 6000 psia)

1.2.1.3 Gaseous O_2 Supply Concept Evaluation (Continued)

Figures C1-6 and C1-7 compare the weight and volume penalties imposed on the PLSS and on the vehicle respectively as a function of PLSS O_2 bottle pressure.

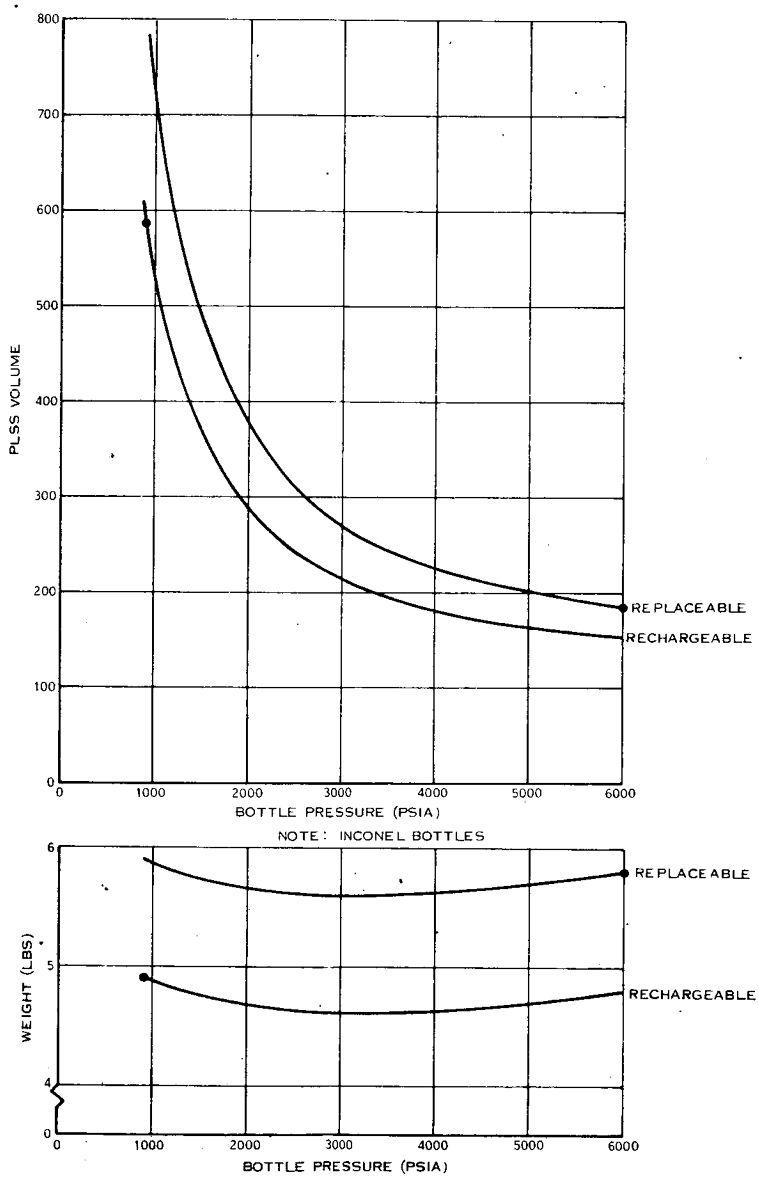

FIGURE C1-6. OXYGEN SUBSYSTEM VOLUME & WEIGHT VS BOTTLE PRESSURE

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1.2.1.3 Gaseous O_2 Supply Concept Evaluation (Continued)

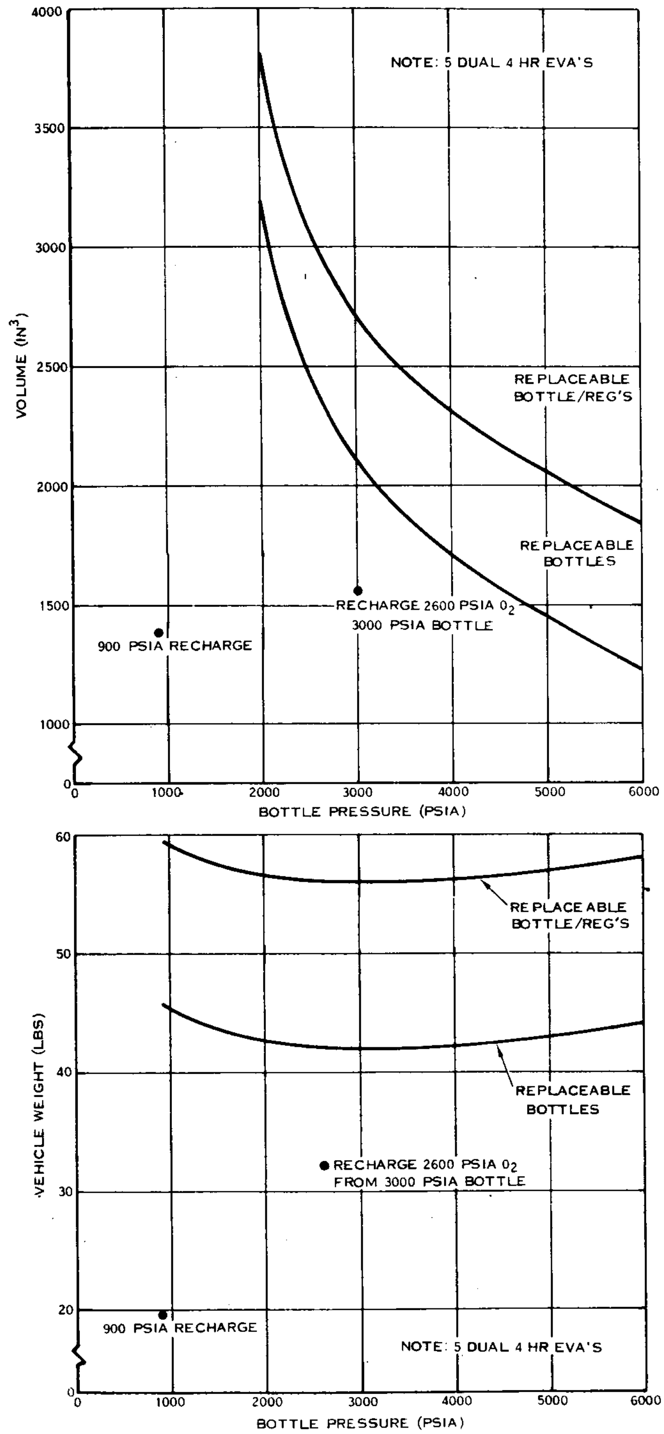

FIGURE C1-7. SHUTTLE WEIGHT AND VOLUME VS BOTTLE PRESSURE

1.2.1.3 Gaseous O_2 Supply Concept Evaluation (Continued)

Based on the data presented in Figures C1-6 and C1-7, the 900 psia O_2 rechargeable concept is recommended. The rationale for this selection is as follows:

a. The replaceable PLSS O_2 supply system is eliminated because it represents the highest weight and volume penalties to the PLSS and to the vehicle.

b. The replaceable O_2 bottle concept, which offers a small vehicle volume savings when used at pressures above 5000 psia, is also eliminated because of the vehicle weight penalties, the operational penalties for bottle change-out and the development costs for a high pressure quick disconnect.

c. The 2600 psia rechargeable concept which offers significant volume saving for the PLSS (340 cu. in.) is eliminated primarily because of the weight and volume penalties imposed on the vehicle. These penalties do not include the penalties for another means of airlock pressurization since this concept prohibits the use of the 3000 psia vehicle gaseous oxygen for airlock pressurization.

d. The 900 psia rechargeable concept results in minimum vehicle weight and volume penalties, utilizes proven equipment technology, and requires no changes to the baseline Orbiter. These advantages warrant its selection in spite of the volume penalty imposed on the PLSS.

Based on the above rationale, the 900 psia rechargeable concept is selected for evaluation with the sodium chlorate candles.

1.2.2 Sodium Chlorate Candles

In this oxygen supply concept, schematically illustrated in Figure C1-8, electrically ignited sodium chlorate candles generate oxygen which charges a pressure vessel surrounding the candles.

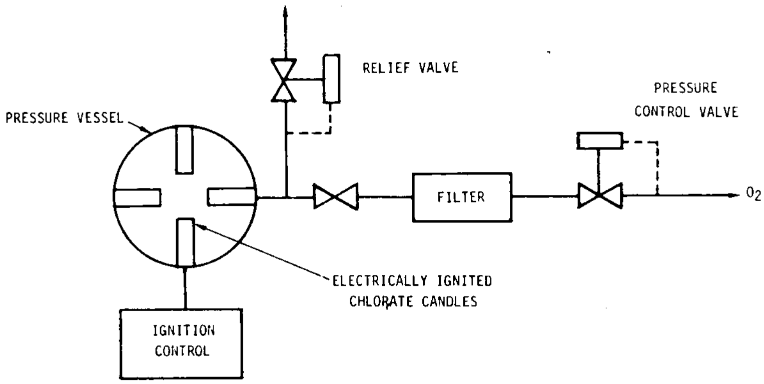

FIGURE C1-8. SODIUM CHLORATE ($NaClO_3$) CANDLE OXYGEN SUPPLY

The chlorate candles produce oxygen at a fixed rate depending on its surface area. Once ignited, the candles produces oxygen through solid decomposition which cannot be terminated prior to complete decomposition. In this concept, four independent candles with ignition systems provide oxygen for a duration of one hour each. This arrangement permits performance of a one hour EVA without expending an additional three hours of oxygen into the Orbiter airlock or cabin. Subsequent EVA's could utilize the remaining portion or a new assembly depending on the particular EVA requirements.

1.2.2 Sodium Chlorate Candles - Continued

With this concept, each candle is sized to produce oxygen at a rate equivalent to the average oxygen requirements of the system. The surrounding pressure vessel serves as an accumulator to handle EVA periods of high oxygen demands. A relief valve prevents over-pressurization of the pressure vessel. Suit pressure control is achieved by means of a demand pressure regulator downstream of the chlorate candles.

The sodium chlorate candles are attractive because of the high density storage of oxygen without the high weight penalties of large pressure vessels and the handling constraints associated with liquid oxygen storage.

The disadvantages of the concept evolves from the constant oxygen production rate which results in an inability to produce sufficient oxygen during periods of very high metabolic work rates or under high system leakage conditions. In addition, the candles produce carbon monoxide which must be removed from the system.

1.2.3 <u>Summary Evaluation and Selection</u>

The two concepts presented are all capable of providing the required oxygen for the Shuttle PLSS. The weights and volumes of the two concepts (900 psi rechargeable and sodium chlorate candles) are compared in Figure C1-9.

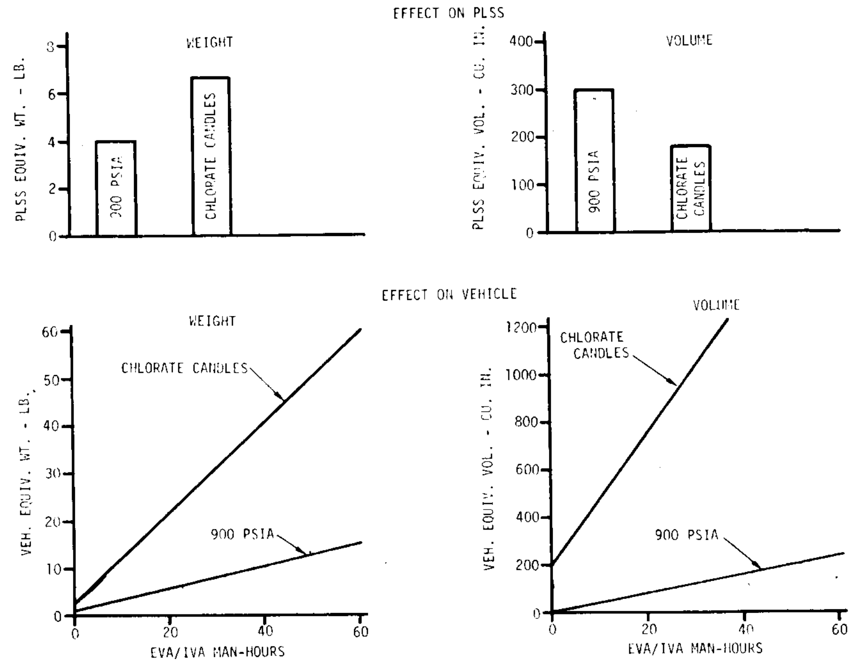

FIGURE C1—9. OXYGEN SUPPLY SUBSYSTEM

1.2.3 Summary Evaluation and Selection (Continued)

These curves are based on the groundrules presented in Table C1-5.

GASEOUS O_2 SUBSYSTEMS
● 900 PSIA STORAGE ● RECHARGEABLE FROM ORBITER SUPPLIES ● PLSS TANK WEIGHT 2.16 LBS/LB of O_2 ● ORBITER TANK WEIGHT 0.25 LBS/LB of O_2
● 6000 PSIA STORAGE ● REPLACEABLE SYBSYSTEM ● PLSS TANK WEIGHT 2.16 LBS/LB of O_2
● SODIUM CHLORATE CANDLES ● CANDLE WEIGHT: 2.63 LBS/LB of O_2 GENERATED

TABLE C1-5. OXYGEN SUPPLY SUBSYSTEM GROUND RULES

From Figure C1-9, it can be seen that the sodium chlorate candles represent the greatest PLSS weight impact and the largest vehicle weight and volume penalties. These penalties, coupled with the development status of this concept, justifies its elimination from further consideration. The 900 psia rechargeable concept is the most attractive concept although it results in the highest volume penalty to the PLSS. The vehicle weight and volume saving and development status of the 900 psia PLSS O_2 subsystem are the primary factors which justify selection of this concept.

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2.0 CO_2 CONTROL SUBSYSTEM EVALUATION

The CO_2 control subsystem of a closed loop PLSS performs the function of maintaining the CO_2 partial pressure of the gas entering the suit to an acceptable level. Concepts evaluated for this function have been divided into four basic categories and are listed in Table C2-1.

I. EXPENDABLES	SOLID SORBENTS 1. HYDROXIDES (LiOH) 2. SUPEROXIDES (KO_2) 3. PEROXIDES (Li_2O_2) 4. OZONIDES LIQUID SORBENT 5. HYDROXIDE SOLUTIONS OPEN LOOP 6. PURGE FLOW
II. REGENERABLES	SOLID SORBENTS 7. ACTIVATED CHARCOAL 8. MOLECULAR SIEVE 9. METALLIC OXIDES ZnO, MgO, $Mg(OH)_2$ 10. SOLID AMINES LIQUID SORBENTS 11. CARBONATE SOLUTIONS 12. LIQUID AMINES
III. ELECTROCHEMICAL	13. HYDROGEN DEPOLARIZED CELL 14. TWO-STAGE CARBONATION CELL 15. ONE-STAGE CARBONATION CELL 16. ELECTRODIALYSIS 17. FUSED SALT
IV. MECHANICAL	18. SIMPLE MEMBRANE DIFFUSION 19. IMMOBILIZED LIQUID MEMBRANE DIFFUSION 20. MECHANICAL FREEZEOUT 21. CRYOGENIC FREEZEOUT

TABLE C2–1 CO_2 CONTROL SUBSYSTEM CONCEPTS

2.0 CO_2 CONTROL SUBSYSTEM EVALUATION - Continued

The requirements specified for the CO_2 control subsystem are summarized in Table C2-2.

REQUIREMENTS:
MAINTAIN INSPIRED CO_2 PARTIAL PRESSURE BELOW 7.6 MM HG
REMOVE 0.82 LBS. OF CO_2
PROVIDE 0.77 LBS. OF O_2 FOR METABOLIC CONSUMPTION AND SYSTEM LEAKAGE

TABLE C2-2. CO_2 CONTROL SUBSYSTEM REQUIREMENTS

Note that a requirement for O_2 production is specified since some of the CO_2 control subsystem concepts also produce oxygen for metabolic consumption. In the weight and volume estimates for these concepts, the selected 900 psia O_2 supply system is incorporated and then reduced depending on the amount of O_2 provided by the CO_2 control subsystem concept.

An initial evaluation based on experience and other studies resulted in the elimination of the electrochemical and mechanical concepts as they are too complex and bulky for an EVA system. In addition, within the expendable category, only lithium hydroxide and lithium peroxide are selected for detailed evaluation as they have the highest theoretical CO_2 removal efficiency and also exhibit the highest actual CO_2 removal efficiency under test or actual usage conditions. Metallic oxides and the solid amines were selected as representative regenerable concepts as past experience indicated they are the most competitive on a weight and volume basis. Thus, this initial evaluation reduced the candidate CO_2 control subsystem candidates to those listed in Table C2-3 below.

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2.0 CO_2 CONTROL SUBSYSTEM EVALUATION - Continued

CONCEPT	REFERENCE PARAGRAPH
EXPENDABLES LITHIUM HYDROXIDE LITHIUM PEROXIDE	2.1
REGENERABLES METALLIC OXIDES SOLID AMINES	2.2

TABLE C2–3 CO_2 CONTROL SUBSYSTEM CONCEPTS

2.1 EXPENDABLE CONCEPTS

Expendable CO_2 control cartridges are sized for a particular EVA mission duration (4 hours for the Shuttle EVA) and are discarded following each EVA

2.1.1 LITHIUM HYDROXIDE (LiOH)

Lithium hydroxide is a solid adsorbent that removes carbon dioxide by the following reactions:

$$LiOH + H_2O\ (g) \longrightarrow LiOH \bullet H_2O$$

$$2\ LiOH\ .\ H_2O + CO_2 \longrightarrow Li_2CO_3 + 3\ H_2O\ (g)$$

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O\ (g)$$

There is a net energy and water vapor production in the process which is removed in the thermal/humidity control subsystem. Figure C2-1 presents a schematic for the LiOH subsystem.

2.1.1 LITHIUM HYDROXIDE (LiOH) - Continued

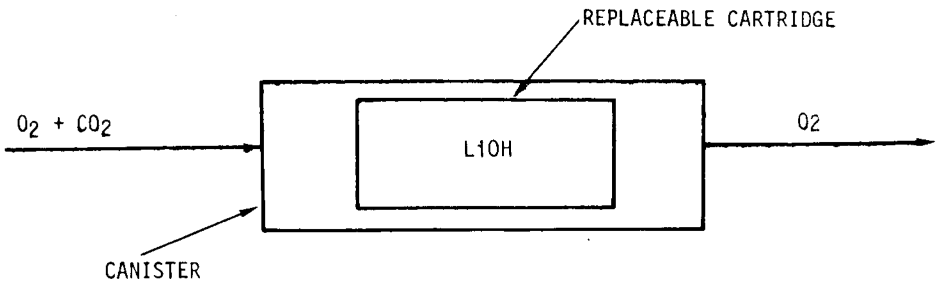

FIGURE C2-1 LiOH CO2 CONTROL SUBSYSTEM SCHEMATIC

From this schematic it can be seen that oxygen mixed with CO_2 enters the canister where the CO_2 is absorbed in accordance with the above reactions. Outlet CO_2 concentration remains near zero for almost 80% of the mission thus providing an extremely low time - averaged CO_2 atmosphere. After each use, the cartridge is replaced in the canister regardless of the total time or use rate accumulated on the unit. This procedure ensures a fully operational charge for each EVA.

2.1.2 LITHIUM PEROXIDE (Li_2O_2)

Lithium peroxide reacts with water vapor and CO_2 for O_2 generation and CO_2 removal, according to the following reactions:

$$Li_2O_2 + H_2O \longrightarrow 2\ LiOH + 1/2\ O_2$$

$$LiOH + H_2O \longrightarrow LiOH \cdot H_2O$$

$$2\ LiOH \cdot H_2O + CO_2 \longrightarrow Li_2CO_3 + 3\ H_2O$$

$$Li_2O_2 + CO_2 \longrightarrow Li_2CO_3 + 1/2\ O_2$$

A non-regenerable solid adsorbent, Li_2O_2 is supplied in cartridges which are replaced after each mission and is schematically defined in Figure C2-2.

2.1.2 LITHIUM PEROXIDE (Li_2O_2) - Continued

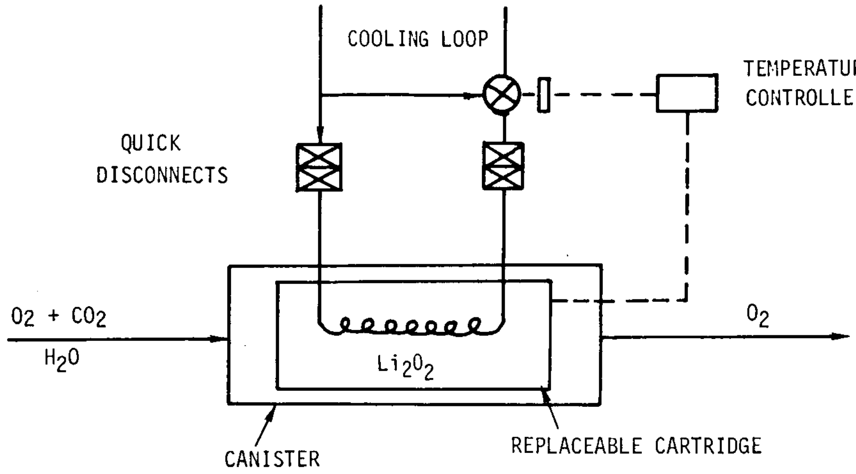

FIGURE C2–2 LiO_2, CO_2 CONTROL SUBSYSTEM SCHEMATIC

Oxygen mixed with CO_2 and water vapor enters the canister where both the CO_2 and water vapor are adsorbed. In addition to CO_2 control, the chemical provides approximtely one-half the metabolic oxygen requirement. This concept requires temperature control of the reacting bed to obtain acceptable performance over widely varying metabolic rates. Low temperature operation minimizes oxygen production while high temperature operation results in excessive O_2 production and poor CO_2 control.

More optimum performance can be obtained by the addition of acatalyst which stimulates O_2 production at lower operating temperature without affecting the CO_2 adsorbtion capability

2.2 REGENERABLE CONCEPTS

Regenerable CO_2 control concepts are those that are not discarded and replaced following each EVA, but rather are regenerated either during operation of the PLSS or in the Orbiter following an EVA. The regenerable concepts considered are listed in Table C2-4 along with the reference paragraphs that discuss each concept.

CONCEPT	REFERENCE PARAGRAPH
METALLIC HYDROXIDE ($Mg(OH)_2$)	2.2.1
METALLIC OXIDE (MgO, ZnO)	2.2.2
SOLID AMINES	2.2.3

TABLE C2–4 REGENERABLE CO_2 CONTROL SUBSYSTEM CONCEPTS

2.2.1 METALLIC HYDROXIDE - Mg $(OH)_2$

Metallic hydroxides such as Mg $(OH)_2$ react with CO_2 according to the following reaction:

$$Mg(OH)_2 + CO_2 \longrightarrow MCO_3 + H_2O + Heat$$

The process is reversible through the following reactions:

$$MgCO_3 + Heat \longrightarrow MgO + CO_2$$

$$MgO + H_2O \longrightarrow Mg(OH)_2 + Heat$$

Figure C2-3 presents a schematic for a metallic hydroxide CO_2 control subsystem for the PLSS.

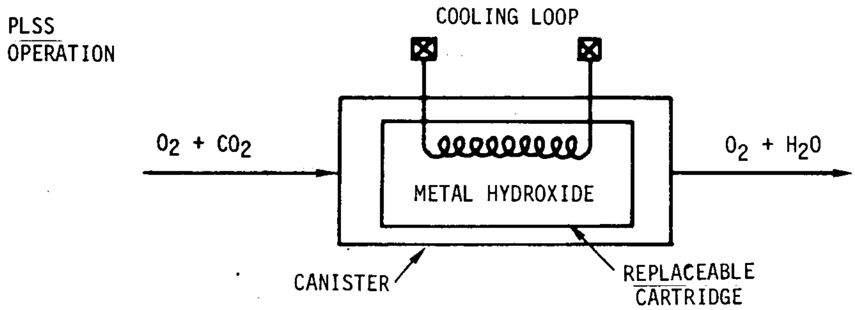

FIGURE C2–3 METAL HYDROZIDE CO_2 CONTROL SUBSYSTEM SCHEMATIC

As can be seen in this schematic, oxygen mixed with carbon dioxide enters a canister containing the metallic hydroxide cartridge where the CO_2 is removed in accordance with the preceding equations. Water vapor is producted as part of the reaction. This concept requires cooling to dissipate the heat of the reaction.

Regeneration is achieved by a two step process in a vacuum oven. First, under heat and vacuum, the carbonate is calcined to the oxide. Then, steam is admitted to the chamber and recirculated at 400 to 900°F, converting the oxide to the hydroxide. The fact that water vapor must be added for regeneration makes this concept impractical for PLSS regeneration, but vehicle regeneration is feasible. Figure C2-4 presents a schematic for such a vehicle regeneration system.

2.2.1 METALLIC HYDROXIDE - $Mg(OH)_2$ - Continued

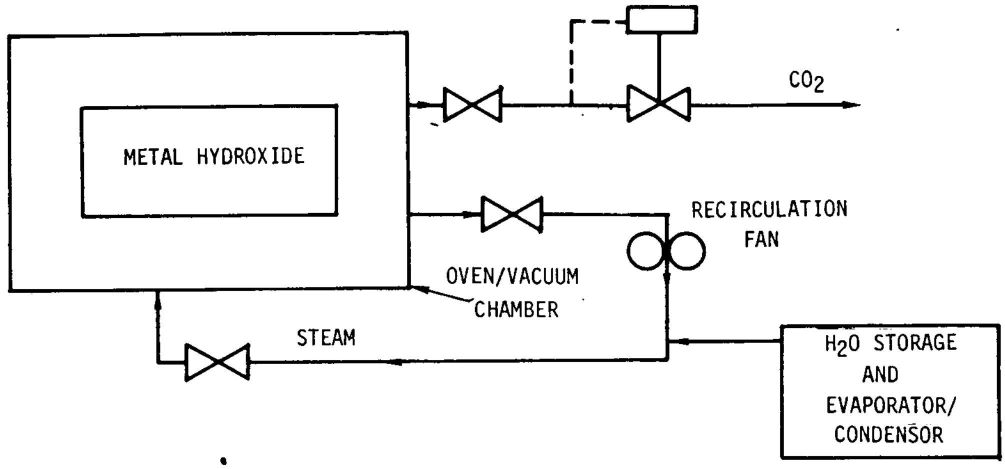

FIGURE C2-4 METAL HYDROXIDE VEHICLE REGENERATION SYSTEM SCHEMATIC

2.2.2 METAL OXIDE - ZnO, MgO

Both zinc oxide and magnesium oxide react with CO_2 according to the following reversible adsorption reactions:

$$ZnO + CO_2 \rightleftharpoons ZnCO_3 + Heat$$

$$MgO + CO_2 \rightleftharpoons MgCO_3 + Heat$$

Figure C2-5 presents a schematic for a metal oxide CO_2 control subsystem for the PLSS.

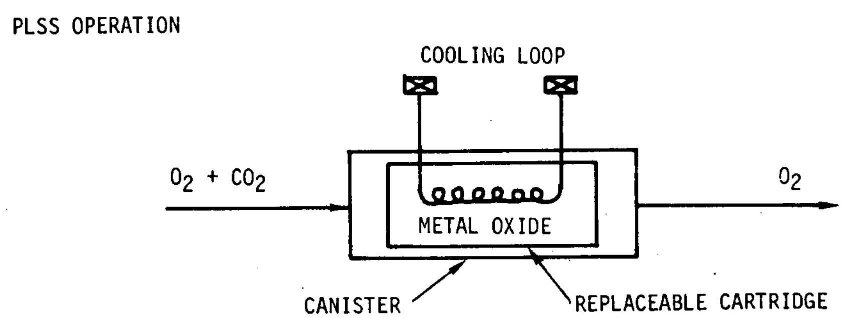

FIGURE C2-5 METAL OXIDE CO_2 CONTROL SUBSYSTEM SCHEMATIC

2.2.2 METAL OXIDE - Z_nO, MgO - Continued

Referring to this schematic, oxygen and CO_2 enter the metal oxide cartridge where the adsorption reaction described above removes CO_2 from the oxygen stream forming a carbonate that remains within the cartridge. Cooling is required to dissipate the heat of this reaction.

Regeneration of the cartridge containing the carbonate is possible either during PLSS operation or in the vehicle following an EVA. Figure C2-6 presents a schematic for vehicle regeneration of a cartridge .

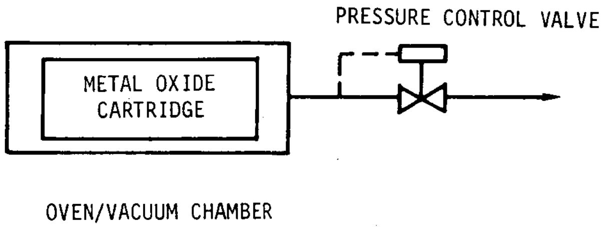

FIGURE C2-6 METAL OXIDE VEHICLE REGENERATION SYSTEM SCHEMATIC

The spent cartridge is vacuum baked driving out the CO_2. A pressure control valve maintains a constant pressure within the oven/vacuum chamber.

Regeneration during PLSS operation requires two metallic oxide cartridges - one adsorbing while the other is being desorbed. Such a cycling concept is schematically depicted in Figure C2-7.

2.2.2 METAL OXIDE - ZnO, MgO - Continued

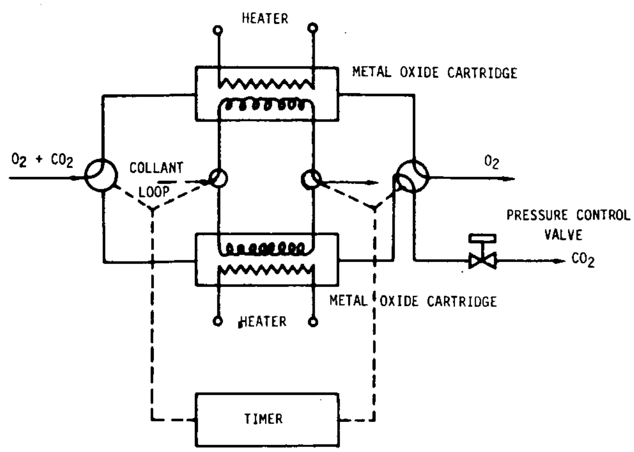

FIGURE C2–7 PLSS REGENERABLE METAL OXIDE CO_2 CONTROL SUBSYSTEM SCHEMATIC

From this schematic it can be seen that two 3-way valves controlled by a timer are utilized to direct the O_2/CO_2 flow to the adsorbing cartridge. The same timer also controls coolant flow to this adsorbing cartridge. At the same time, the cartridge that is being desorbed is heated and regenerated with the CO_2 being dumped through a pressure control valve.

Excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future development effort. For this study, the adsorbent was contained between screens with gas flow over rather than through the packing. CO_2 diffusion into the thin oxide bed may be sufficient as long as the solid volume transition during adsorb/desorb does not result in an impregnable surface or if an extremely fine screen is used. An alternate concept would consider a carrier to stabilize the solid adsorbent -- possibly a thin layer of the oxide flame-sprayed on a screen matrix.

2.2.3 SOLID AMINES

The solid amines is a CO_2 removal concept that utilizes an amino compound deposited on an inert carrier to form a stable adsorbent bed. Three (3) sets of reactions occur in the adsorbed film:

Primary Amino Groups

(1) $RNH_2 + H_2O \longrightarrow RNH_3 \bullet OH$

(2) $RNH_3OH + CO_2 \rightleftharpoons RNG_3 \bullet HCO_3$

Secondary Amino Groups

(1) $R_2NH + H_2O \rightleftharpoons R_2NH_2OH$

(2) $R_2NH_2OH + CO_2 \rightleftharpoons R_2NH_2 \bullet HCO_3$

Tertiary Amino Groups

(1) $R_3N + H_2O \qquad R_3NHOH$

(2) $R_3NHOH + CO_2 \qquad R_3NH \bullet HCO_3$

Figure C2-8 presents a schematic for a solid amine CO_2 control subsystem for the PLSS.

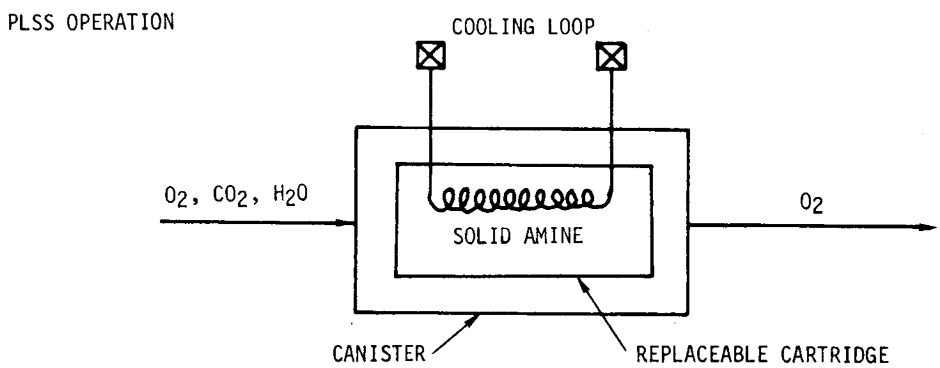

FIGURE C2-8 SOLID AMINE CO_2 CONTROL SUBSYSTEM SCHEMATIC

2.2.3 SOLID AMINES - Continued

In this system, oxygen mixed with CO_2 and water vapor enters the solid amine cartridge where both the CO_2 and water vapor are adsorbed. Cooling is required in this concept to dissipate the heat of the reaction.

The water removed by this concept is an unattractive feature and tends to completely dehumidity the ventilation loop. Excessive dehumdification not only causes crewman discomfort, but also reduces the sorbent's capacity for CO_2 removal.

Regeneration of the solid amine can be achieved either in the vehicle following an EVA or during operation of the subsystem during an EVA. Figure C2-9 presents a schematic for vehicle regeneration utilizing a vacuum bake-off.

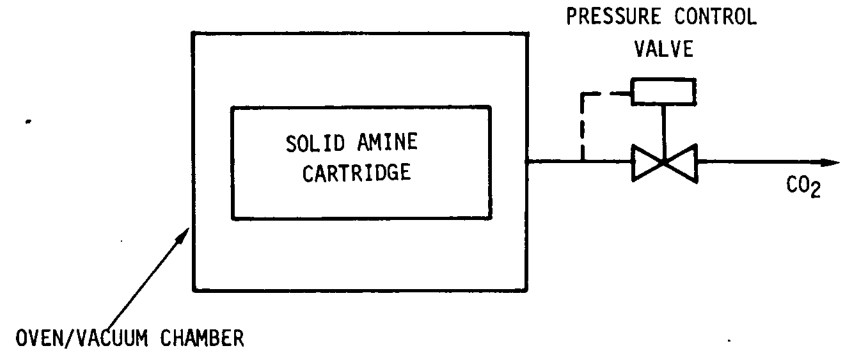

FIGURE C2–9 SOLID AMINE VEHICLE REGENERATION SYSTEM SCHEMATIC

During this regeneration process, the adsorbing reactions proceed in the reverse direction with CO_2 and water vapor being driven off and dumped through a pressure control valve. Regeneration of the solid amines during operation is possible and a concept for such a PLSS system is schematically presented in Figure C2-10.

2.2.3 SOLID AMINES - (Continued)

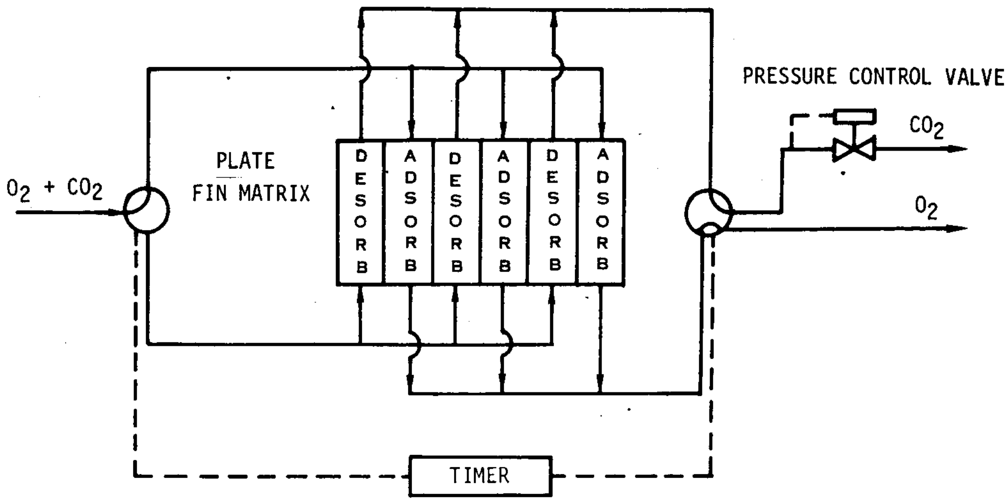

FIGURE C2-10 PLSS REGENERABLE SOLID AMINE CO_2 CONTROL SUBSYSTEM SCHEMATIC

As can be seen from this schematic, alternate adsorb and desorb cartridges are utilized to achieve both CO_2 removal and regeneration simultaneously. A timer controlling two three-way valves cycles the amine cartridges between adsorb and desorb functions. Utilization of alternate flow passages containing adsorbing and desorbing material results in an isothermal adsorb/desorb process. Energy released from the adsorbing passages is transferred by conduction through the metal matrix to the desorbing material to supply the requirements of the endo/thermic desorption. This concept neither imposes a thermal load on the PLSS thermal control subsystem nor requires additional energy for regeneration. In addition, it also provides humidity control.

2.2.4 REGENERABLE CO_2 CONTROL SUBSYSTEM SELECTION

Table C2-5 presents a listing of the regenerable CO_2 control subsystem concepts under consideration.

2.2.4 REGENERABLE CO_2 CONTROL SUBSYSTEM SELECTION - Continued

$Mg(OH)_2$	VEHICLE REGENERABLE
MgO	PLSS & VEHICLE REGENERABLE
ZnO	PLSS & VEHICLE REGENERABLE
SOLID AMINES	PLSS & VEHICLE REGENERABLE

TABLE C2–5 REGENERABLE CO_2 CONTROL SUBSYSTEM CONCEPTS

The purpose of this section is to evaluate these regenerable concepts and select the best concept to evaluate against the selected non-regenerable concepts (LiOH & Li_2O_2) in Section 2.3. Since all of the regenerable concepts are capable of achieving the desired CO_2 removal function and are about the same complexity, sizing is the principle tradeoff parameter involved in a selection. The sizing criteria utilized are listed below:

a. Utilization of 55% of maximum theoretical capability

b. PLSS regeneration at 15 minute intervals

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2.2.4 REGENERABLE CO_2 CONTROL SUBSYSTEM SELECTION - Continued

Figure C2-11 presents a vehicle and PLSS weight and volume tradeoff between competing subsystems.

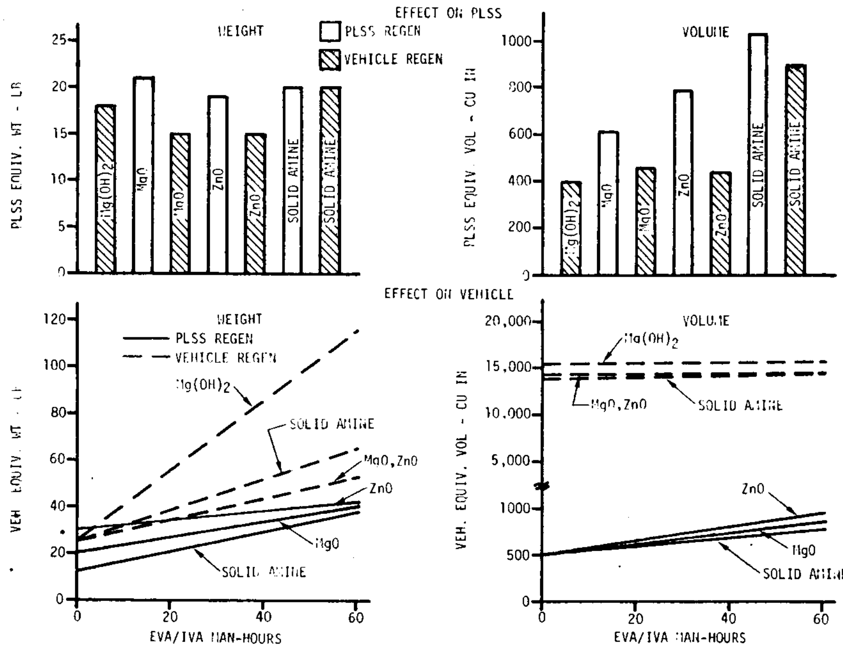

FIGURE C2-11 REGENERABLE CO_2 CONTROL CONCEPTS — WEIGHT & VOLUME TRADEOFFS

From these curves it can be seen that all of the vehicle regenerable system impose a significant vehicle weight and volume penalty over the PLSS regenerable concepts. For this reason the vehicle regenerable concepts are eliminated. Removing these systems results in the weight and volume tradeoff presented in Figure C2-12.

2.2.4 REGENERABLE CO_2 CONTROL SUBSYSTEM SELECTION - Continued

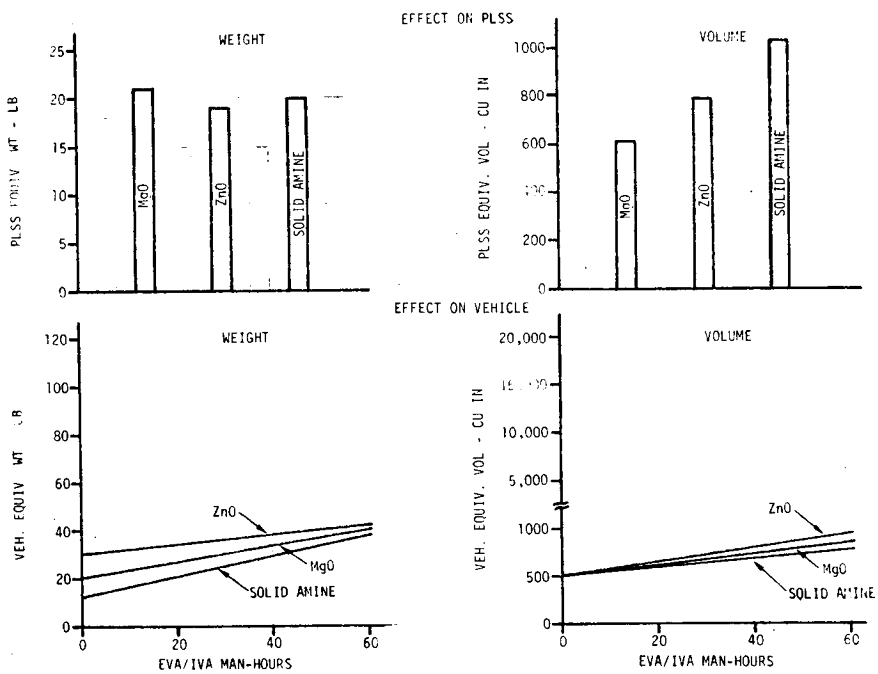

FIGURE C2–12 REGENERABLE CO2 CONTROL CONCEPTS — WEIGHT & VOLUME TRADEOFFS

From these curves, it can be seen that the PLSS volume penalty of the solid amine system is significantly higher than the metallic oxides and for this reason it is eliminated. The magnesium oxide system is selected over the zinc oxide concept primarily because of the 200 cubic inch PLSS volume savings it provides.

2.3 CO_2 CONTROL SUBSYSTEM SELECTION

The purpose of this section is to select the best approach for PLSS CO_2 control. The concepts involved in this final selection phase include two nonregenerative systems and one regenerable concept. Table C2-6 lists the concepts under consideration.

2.3 CO_2 CONTROL SUBSYSTEM SELECTION - Continued

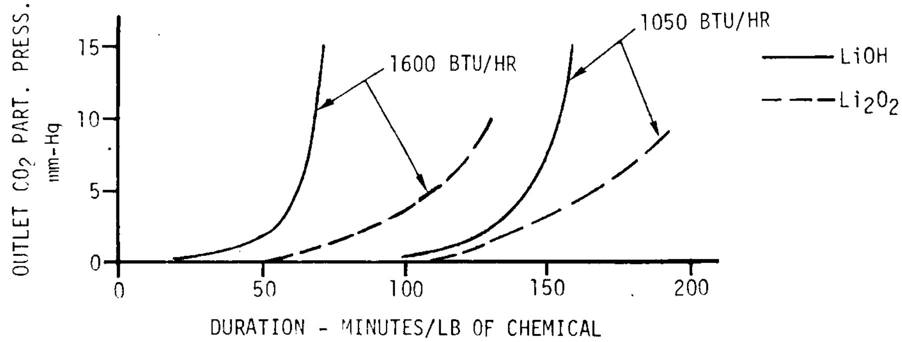

FIGURE C2—13 NONREGENERABLE SORBENT UTILIZATION

Figure C2-14 presents a PLSS and vehicle weight and volume comparison between the CO_2 control subsystem concepts.

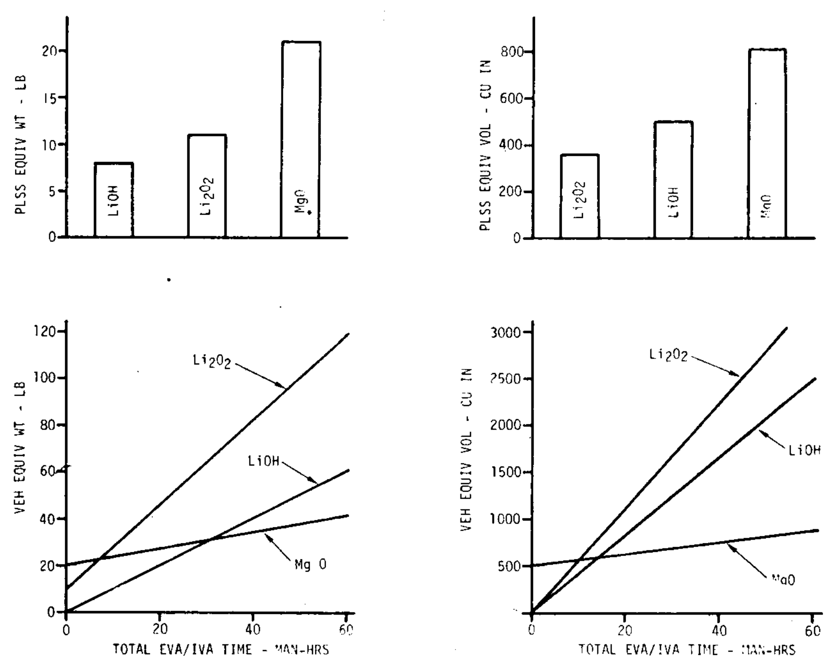

FIGURE C2—14 FINAL CO2 CONTROL CONCEPTS — WEIGHT & VOLUME TRADEOFFS

2.3 CO_2 CONTROL SUBSYSTEM SELECTION - Continued

NON-REGENERATIVE
LITHIUM HYDROXIDE (LiOH)
LITHIUM PERODIXE (Li_2O_2)
REGENERABLE
MAGNESIUM OXIDE (MgO)

TABLE C2–6 COMPETITIVE CO_2 CONTROL CONCEPTS

The evaluation criteria include size, weight, cost and development status. The sizing assumptions utilized are contained in Table C2-7.

REGENERABLE SUBSYSTEMS
UTILIZATION OF 55% OF MAXIMUM THEORETICAL CAPACITY
PLSS REGENERATION AT 15 MINUTE INTERVALS
NON-REGENERABLE SUBSYSTEMS
UTILIZATION PER FIGURE C2-13

TABLE C2–7 SIZING ASSUMPTIONS

2.3 CO_2 Control Subsystem Selection - Continued

Based on this evaluation, LiOH is the selected CO_2 control subsystem for the Shuttle EVA requirements. The reasons for this selection are:

a. LiOH imposes the minimum PLSS weight and volume penalty

b. LiOH provides the minimum vehicle weight penalty for flights requiring less than 30 man hours of EVA

c. LiOH has the minimum vehicle volume penalty for flights with less than 15 man hours of EVA

d. LiOH has been proven on previous manned space programs

e. The use of LiOH eliminates development costs associated with other candidate subsystems

3.0 THERMAL CONTROL SUBSYSTEM - EVALUATION

The thermal control subsystem maintains thermal equilibrium of the suited crewman and provides PLSS equipment cooling as required. Specific thermal loads imposed on this subsystem consist of the crewman's metabolic load, PLSS equipment loads, and the inward environmental heat leak. The detailed thermal requirements are specified in Table C3-1.

PARAMETER	REQUIREMENT
INTEGRATED THERMAL LOAD	7120 BTU
PEAK THERMAL LOAD	2900 BTU/HR
AVERAGE THERMAL LOAD	1480 BTU/HR
MINIMUM THERMAL LOAD	760 BTU/HR
SUIT INLET DEWPOINT	50°F MAX
PROVIDE VARIABLE LCG INLET TEMPERATURES	

TABLE C3—1 THERMAL CONTROL SUBSYSTEM REQUIREMENTS

Thermal control areas have been divided into three basic categories to facilitate concept identification and evaluation:

- Expendable
- Radiation
- Thermal Storage

In addition, a fourth category entitled "hybrid" is also included. Hybrid subsystem concepts are a combination of two or more concepts from any of the three basic categories.

3.0 THERMAL CONTROL SUBSYSTEM - EVALUATION - Continued

Table C3-2 presents a listing of the various concepts investigated in each of these four categories.

I. Expendables

Water

1. Water Boiler
2. Super-Cooled Water Boiler
3. Super-Cooled Water Boiler with Vapor Regnerative Cooling
4. Water Sublimator
5. Super-Cooled Water Sublimator
6. Super-Cooled Water Sublimator with Vapor Regenerative Cooling
7. Plate Fin Flash Evaporator
8. Nonsteady State Pulse Feed Flash Evaporator
9. Static Vortex Flash Evaporator
10. Turbine-Rotary Vortex Flash Evaporator
11. Motor-Rotary Vortex Flash Evaporator
12. Multi-Stage Flash Evaporator
13. Vapor Diffusion Through Suit Pressure Valves
14. Vapor Diffusion Through Water Permeable Membrance

Hydrogen Peroxide (H_2O_2)

15. H_2O_2 Dissociation into H_2O and O_2

Ammonia (NH_3)

16. NH_3 Boiler
17. NH_3 Sublimator

Carbon Dioxide (CO_2)

18. CO_2 Boiler
19. CO_2 Sublimator

Methane (CH_4)

20. CH_4 Sublimator

Cryogenics

21. Cryogenic O_2
22. Cryogenic H_2

II. Radiation

Direct Cooling

23. LCG
24. Heat Pipe
25. Water Adsorption Utilizing
    26. $LiCl \cdot 3H_2O$
    27. $CaCl \cdot 6H_2O$
    28. Molecular Sieve
    29. Silica Gel
    30. $LiBr \cdot 3H_2O$
    31. $Na_2Se \cdot 1\ H_2O$

Indirect Cooling

32. Vapor Compression Refrigeration Cycle Using Freon
33. Water Adsorption Cycle Using NH_3
34. Water Adsorption Cycle Using LiBr
35. Brayton Cycle Using Air

III. Thermal Storage

36. Ice
37. Subcooled Ice
38. Thermal Wax - Transit 86
39. Eutectic Salt - Sodium Sulphate ($NA_2SO_4 \cdot 10H_2O$)
40. Phosphonium Chloride (PH_4Cl)
41. Hydrogen (H_2)

IV. Hybrids

42. Expendable/Radiation - Direct Cooling
43. Expendable/Radiation - Indirect Cooling
44. Expendable/Thermal Storage
45. Radiation/Thermal Storage
46. Thermal Storage/Water Adsorption

TABLE C3-2 THERMAL CONTROL SUBSYSTEM CONCEPTS

3.1 INITIAL EVALUATION

To reduce the number of concepts listed in Table C3-2, an initial evaluation was made based on past experience gained through spacecraft system and EVA system studies. Following are the results of this initial evaluation.

Expendable Concepts

The expendable water subsystems (with the exception of vapor diffusion through a permeable membrane - which requires an extremely large membrane surface area) appear to be the only competitive expendable subsystems. They are lighter and smaller, represent a minimum vehicle impact, and present no appreciable handling or operational problems. In addition, concepts requiring other expendables than water probably will not be sufficiently developed by 1975. The expendable water concepts chosen for further evaluation (Section 3.1) are the water boiler, the water sublimator and the flash evaporator. The expendable water concepts utilizing vapor regenerative cooling, super-cooling, and vapor diffusion were eliminated because they provide little or no advantage over the selected concepts and are more complex.

Radiation Concepts

Initial evaluations of the radiation concepts show that surface areas ranging from 12 to 17 square feet are required. This size radiator is considered impractical for an EVA system and would not be functional during IV operations. The radiator concepts also require proper orientation and are susceptible to surface degradation and contamination. Therefore, all radiator concepts were eliminated from further consideration.

Thermal Storage Concepts

Thermal storage concepts utilize the latent heat of fusion and/or the sensible heat capacity of a material to reject heat. Only the concept utilizing an easily removable module, with ice as the heat absorbing medium, was selected for further evaluation since it shows the most competitive PLSS weight. The other phase change materials were rejected primarily due to weight, volume, availability or hazardous characteristics for spacecraft use.

3.1 INITIAL EVALUATION - Continued

Hybrid Concepts

The most attractive of the hybrid concepts investigated are:

a. Expendable/Radiation - Heat Pump
b. Expendable/Thermal Storage - Ice

However, these concepts offer no advantage over the expendable water concepts since they are heavier, larger, more costly, and each relies in part on expendable materials for heat rejection. Thus all the hybrid concepts were eliminated from further consideration.

3.2 DETAILED EVALUATION

The preceding section presented the thermal control subsystem concepts investigated. Based on an initial evaluation, the following concepts were selected for further evaluation:

- Water Boiler
- Water Sublimator
- Flash Evaporator
- Thermal Storage - Ice

The purpose of this section is to present a detailed description of each of these concepts and select the most desirable approach for the Shuttle PLSS.

3.2.1 Water Boiler

The water boiler, shown schematically in Figure C3-1, is an expendable thermal control concept that utilizes the heat of vaporization of water to satisfy the system heat rejection requirements.

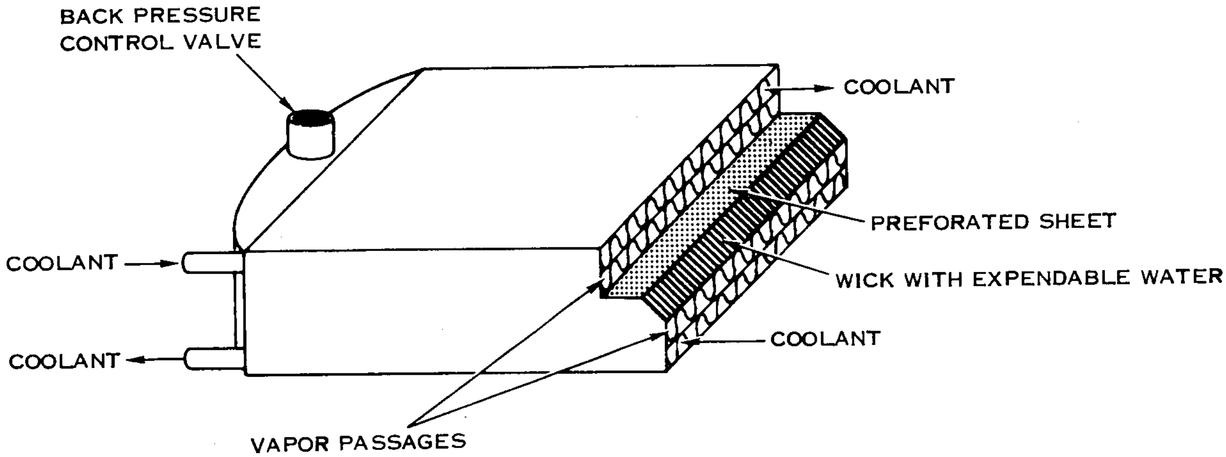

FIGURE C3–1 WATER BOILER SYSTEM SCHEMATIC

The boiler can either be wick-fed or pressure fed and acts as a storage vessel for the expendable water. The boiling temperature of this water is controlled by a Back Pressure Valve (BPV), which reacts to either steam outlet temperature or boiling chamber pressure. A manual temperature control valve is included to permit adjustment of the LCG flow loop temperature. Water that is condensed and separated from the suit vent loop can be fed into the boiler to provide additional capacity. A relief valve serves to protect against overpressurization due to storage temperature fluctuations. Recharging of the water boiler can introduce excessive water carry-over at start-up depending on the recharging concept employed. The charging of water, under pressure, directly on the wicking material can result in filling of the vapor passages and the water boiler up to the back pressure control valve. Upon start-up, carry over occurs since the excess water escapes through the back pressure control valve. Potential solutions to this problem have been identified and include: venting the excess

3.2.1 Water Boiler - Continued

water overboard through a vacuum line prior to start-up; draining the excess water to the vehicle waste management system prior to start-up; removing the wicking material and filling within a container prior to inserting into the water boiler; and use of pre-charged expendable wicking cartridges which are inserted into the boiler prior to each EVA. Further evaluation of this problem and the selection of the recharging concept would be accomplished as part of a preliminary design effort.

At lower system heat loads, it is necessary to reduce the rate of expendable water boiling to prevent freeze-up. A means to control the rate of heat rejection is to incorporate an automatic valve at the exhaust of the water boiler to back pressure the boiling surface and raise the boiling temperature.

An attractive feature of the water boiler is that it can be designed for cartridge installation of the wicking material. This approach minimizes the potential wick degradation problem and simplifies any special servicing, such as system dry-out or bacteriacide treatment, since the wicking portion can be easily removed from the PLSS for servicing.

3.2.2 Water Sublimator

The water sublimator, shown schematically in Figure C3-2, is an expendable thermal control concept that utilizes the heat of sublimation to provide direct cooling of the LCG and suit vent loops.

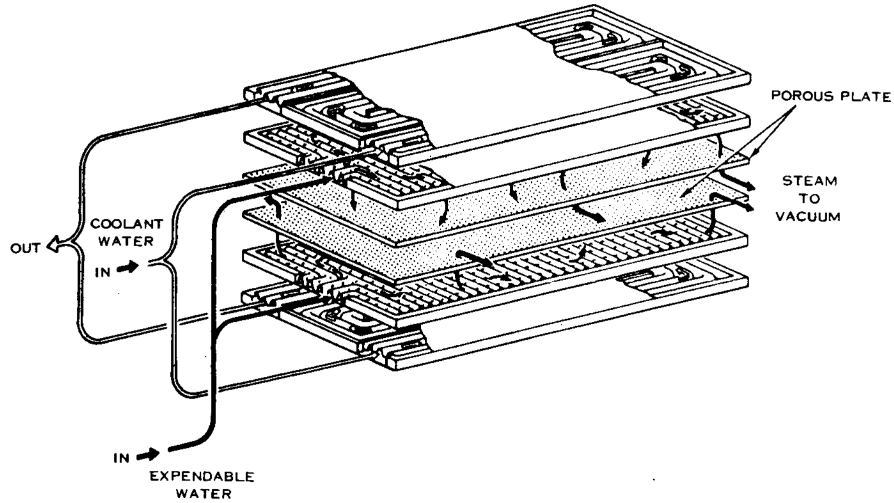

FIGURE C3—2 WATER SUBLIMATOR SCHEMATIC

3.2.2 Water Sublimator - Continued

The sublimator contains a porous plate which is exposed to space vacuum on one side and expendable water on the opposite side. The expendable water within the porous plate freezes and then sublimates to space vacuum as heat is applied. Additional expendable water freezes and maintains an ice layer in the sublimator which is proportional to the amount of heat added to the heat exchanger. As the heat load is reduced, the ice layer thickness increases, thereby reducing the thermal conductivity and the amount of heat being rejected by the unit. This feature is the primary advantage of the sublimator since it is self regulating and eliminates the need for back pressure devices or complex control systems.

The primary concern with water sublimators, as currently constructed, is the susceptibility to corrosion and contamination. Based on data from sublimators of the Apollo LM and PLSS systems, a life expectancy of approximately 300 hours of operation is estimated. Although the mechanisms which result in sublimator degradation are not fully known, it is believed that corrosion of the porous material occurs and products of corrosion then contaminate the unit by blockage of the pores. Potential concepts for increasing sublimator life have been identified and include stainless steel porous material, non-metallic porous media, and redesigning the assembly to permit easy replacement of the porous plates. Evaluation of these concepts is required as part of preliminary design and development activities.

Dissolved and free gases in expendable water is not expected to cause sublimator performance problems based on flight experience with sublimators in both the Apollo LM and PLSS systems. However, these gases can affect other subsystem performance including displacement of expendable water and improper separated water-control if the storage of separated water relies on collapsing of a bladder as in the Apollo PLSS. If such a system is used, a trapped gas bubble of sufficient size and pressure will prevent bladder collapse and preclude water transfer from the water separator to the storage reservoir. This could result in free water entering ventilation loop components such as the fan and LiOH cartridge to degrade their performance.

3.2.3 Flash Evaporator

A flash evaporator concept is shown in Figure C3-3.

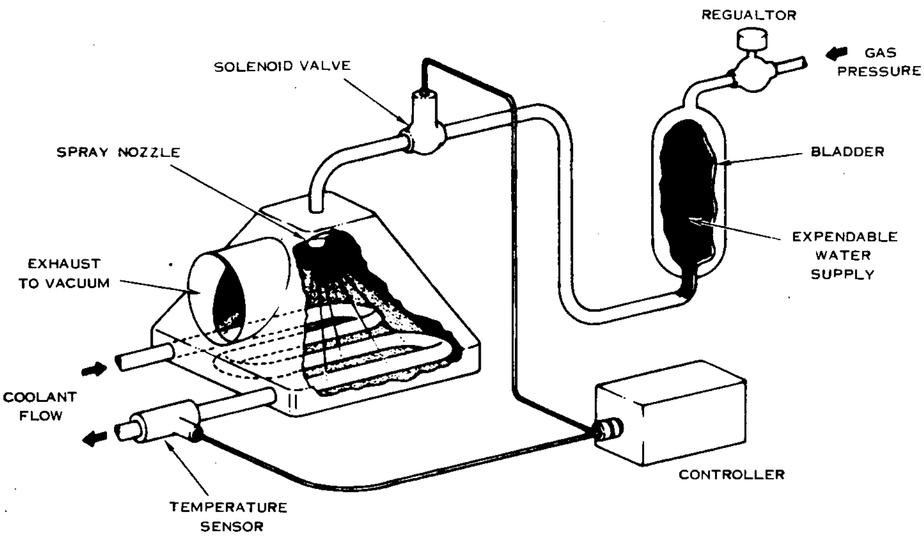

FIGURE C3—3 FLASH EVAPORATOR SCHEMATIC

The flash evaporator has the capability of dissipating a significantly higher heat load per unit of exposed surface area than either of the other two concepts. This is accomplished by spraying a thin film of water on to a surface which is exposed to vacuum. The water film boils immediately to cool the exposed surface and the recirculating coolants used by the system. Optimum performance of the flash evaporator requires that a spray nozzle evenly distribute a thin film of water over the surface and that the film be maintained very thin such that freezing does not occur. Development tests indicated that these conditions can be satisfied by a pulsing spray rather than a continuous spray since the pulsing spray concept allows time for the water film to boil away before a second water film is added. The spray nozzle requires a pressure above 50 psia to effectively distribute a thin film over the surface. To handle varying heat loads, the flash evaporator requires a control system which varies the duration of spray on-time or off-time. For the EVA system, the control system could be designed to maintain a constant fluid temperature at the coolant outlet of the flash evaporator. Free gas in the expendable water supply is not expected to cause performance problems.

3.2.3 Flash Evaporator - Continued

The disadvantage of the flash evaporator is that the control system is considerably more complex than in either of the other concepts. The control system complexity is further complicated by the comparatively low heat loads of the EVA system which require the use of an extremely small nozzle orifice and short spray pulse. The concept also requires additional energy for pressurization of the expendable water supply to obtain good nozzle performance. This energy (gaseous pressure source or pump power) is an additional penalty to the system.

3.2.4 THERMAL STORAGE - ICE

This is a regenerable thermal control concept that utilizes the heat of fusion of ice and the heat capacity of water to provide thermal control. This concept is schematically presented in Figure C3-4.

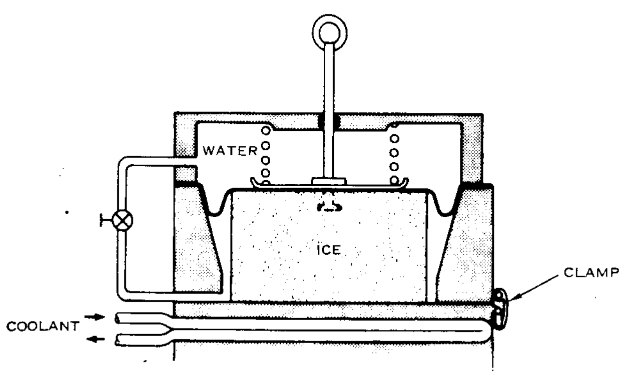

FIGURE C3–4 ICE CHEST SCHEMATIC

3.2.4 THERMAL STORAGE - ICE - Continued

From this schematic it can be seen that direct cooling of the system is achieved in the thermal storage unit by melting ice. A slight preload is applied to the contained ice to ensure direct contact with the heat exchanger surface. As the ice melts, the preload forces the water to the opposite side of the diaphragm.

For regeneration, the diaphragm is manually returned to the original position which forces the water under the diaphragm prior to refreezing. The unit is separated from the PLSS package by releasing clamps. This approach precludes freezing of the PLSS coolant while refreezing the melted ice.

This concept is not competitive with the expendable water concepts in regards to weight, volume and vehicle impacts and will be considered further only as a means of supporting EVA with contamination sensitive payloads since water vapor venting is not required with this concept.

3.3 SUMMARY

The three (3) expendable water thermal control concepts presented are all capable of providing thermal control for the Shuttle PLSS. A summary comparison of weights and volumes are presented in Figure C3-5.

The thermal storage/ice concept is not competitive with the three (3) expendable water concepts as a primary means of thermal control. However, it is a viable concept for EVA missions with contamination sensitive payloads and will be considered as a candidate for these missions.

3.3 SUMMARY - Continued

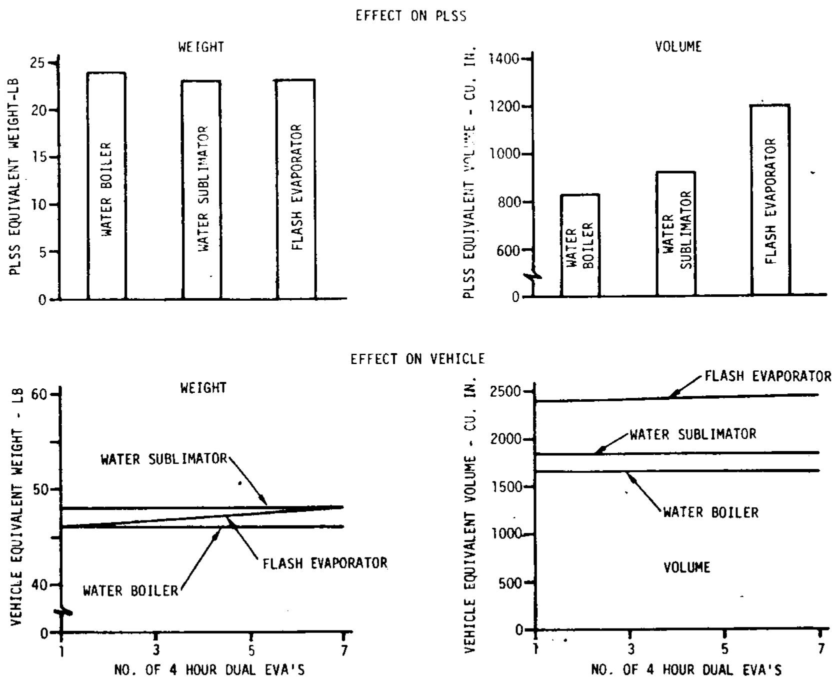

FIGURE C3—5. THERMAL CONTROL SUBSYSTEM WEIGHT & VOLUME COMPARISON

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APPENDIX D

EMERGENCY LIFE SUPPORT SYSTEM

BOTTLE PRESSURE TRADE-OFF

1.0 EMERGENCY LIFE SUPPORT SYSTEM (ELSS) BOTTLE PRESSURE TRADE-OFF STUDY

An analysis of ELSS weight and volume for various ELSS bottle pressures was conducted and the results are presented in Figures D-1 and D-2, respectively. These curves are based on the following assumptions:

a. Suit ventilation flow - 3.2 cfm at 8.0 psia for 15 minutes.

b. Bottle material - Inconel 718.

c. Proof and burst pressures are 1.5 and 2.0 times normal operating pressures, respectively.

d. Constant entropy process simulating a rapid blowdown in zero gravity with an initial bottle temperature of 70°F.

For purposes of this trade-off evaluation, pressure gage accuracy, external leakage, variations in pressure regulation band and variations in flow limiting orifice are not reflected in the subject curves.

As can be seen from Figure D-1, a pressure of 3000 psia s the point at which the bottle plus oxygen weight is a minimum. However, an ELSS volume reduction of approximately 33% (see Figure D-2) can be achieved with a weight increase of less than 1.5 pounds by utilizing a bottle pressure of approximately 6000 psia. Beyond 6000 psia the bottle volume is nearly asymptotic and there are no significant volume savings.

1.0 EMERGENCY LIFE SUPPORT SYSTEM (ELSS) BOTTLE PRESSURE TRADE-OFF STUDY (CONTINUED)

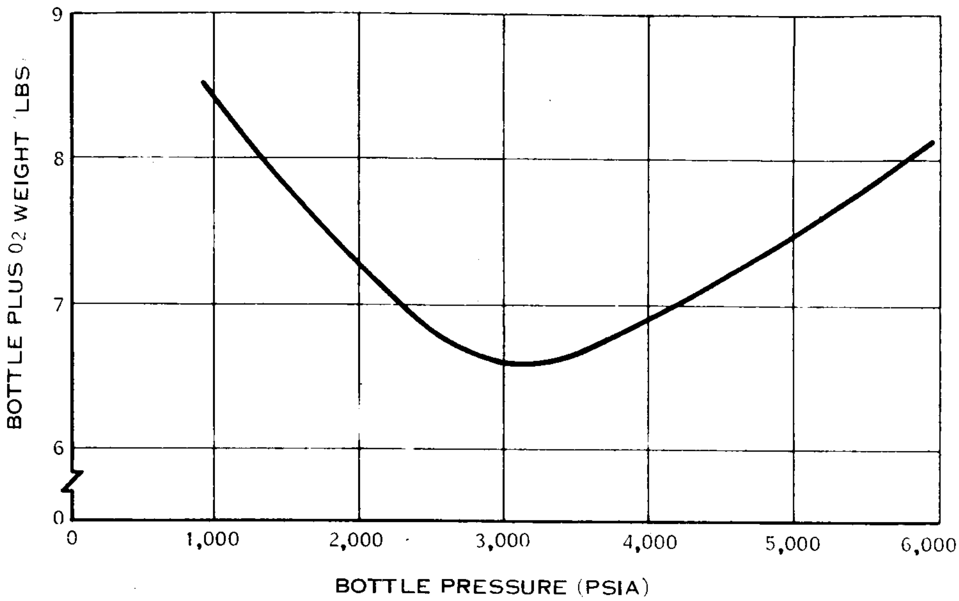


FIGURE D-1. ELSS SUPPLY PRESSURE VS WEIGHT

1.0 EMERGENCY LIFE SUPPORT SYSTEM (ELSS) BOTTLE PRESSURE TRADE-OFF STUDY (CONTINUED)

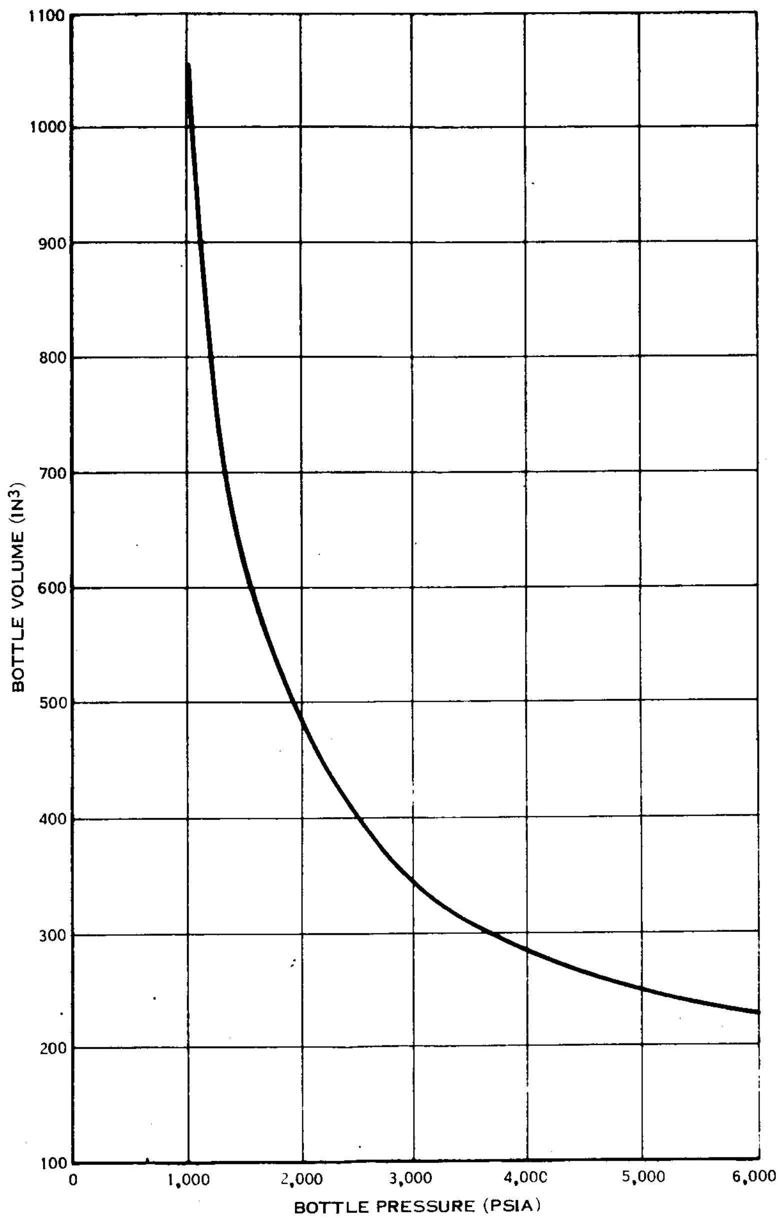


FIGURE D–2. ELSS SUPPLY PRESSURE VS VOLUME

APPENDIX E

CREWMAN AND EQUIPMENT RESTRAINTS

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

1.0 HANDHELD RESTRAINT DEVICES

1.1 HANDRAILS

DESCRIPTION

Handrails with a rectangular or oval cross section were evaluated as excellent mobility aids for Gemini and Apollo. It was determined that these rails should be set off from the surface at least 2.25 inches to permit ease of use. They may run the entire length of travel desired or may be in sections. They also offer good temporary restraint. The parallel handrails as shown in Figure E-1 provide much better control during translation, than the single handrail, although the single rail is adequate.

Weight: 0.85 lbs/ft
Volume: 0.0005 ft^3/ft

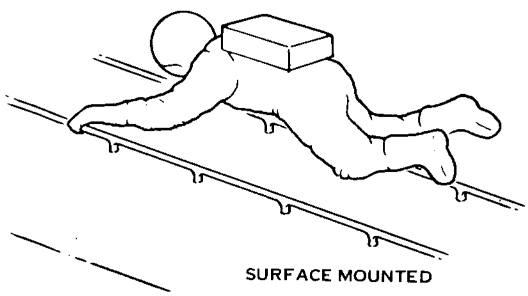


FIGURE E-1. HANDRAILS

Testing

Qualified - Use on Gemini and Apollo

Merits	Deficiencies
Requires no electrical power	Requires use of one or both hands
Light weight	Difficult to manage large packages
Durable	Structural interface with vehicle - should be incorporated in vehicle design
Reliable	
Simple	
Maintenance Free	
Applicable at all levels of Gravity	
Positive control	

1.2 HANDHOLDS

Description

As shown in Figure E-2, handholds can be either recessed or protruding depending on intended use. For mobility, the recessed type would be better since they don't present "elbow knockers". For restraint, the protruding type would probably afford a better purchase and is an excellent temporary restraint. The protruding type is usually 1/2 to 1-1/2 inches in diameter and 4-1/2 inches inside width, set off the surface at least2.25 inches.

Weight: 0.85 lbs
Volume: 0.0005 ft^3

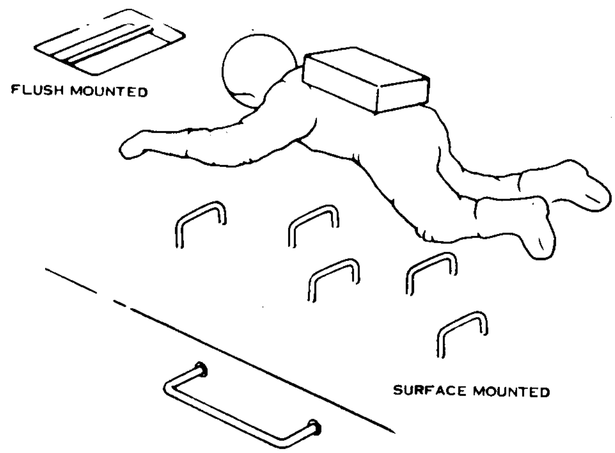


FIGURE E–2. HANDHOLDS

Testing

Qualified - Used on Gemini and Apollo

Merits	Deficiencies
Requires no electrical power	Requires use of one or both hands
Light weight	Difficult to manage large packages
Durable	Structural interface with vehicle - should be incorporated in vehicle design
Reliable	
Simple	
Maintenance Free	
Applicable at all levels of Gravity	
Positive control	

Handrails and handholds have been fully developed and flight qualified during the Gemini and Apollo programs. They provide excellent temporary restraint for transition to a hands free restraint system. They also provide ready-made attach points for tethers and can be used for stability aids throughout the vehicle.

1.3 LADDER AND RAIL COMBINATION

Description

The ladder shown in Figure E-3 is made from individual rungs bent in the shape shown. A vertical handrail extends the length of the ladder as shown. The bent shape of each rung allows continuous gripping of the vertical handrail during ascent and descent of the ladder.

Weight: 1.6 lbs/ft
Volume: 0.3 ft^3/ft

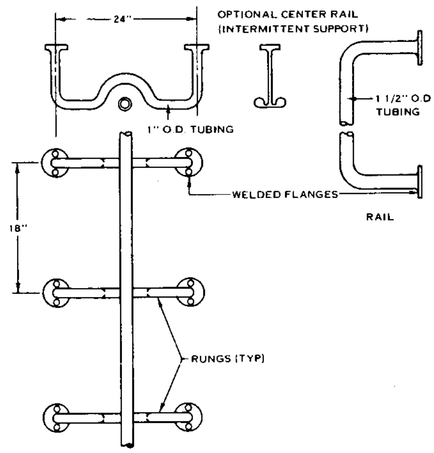


FIGURE E–3. LADDER/RAIL COMBINATION

Merits	Deficiencies
Uses no electrical power	Requires at least one hand
Simple - Durable	Direction of ladder traffic determined by coriolis effect in artificial gravity environment -- requires dual installation or access to both sides of ladder
Reliable	Structurally attached to vehicle
Maintenance free	Location and required passageways should be included in basic design
Usable in all gravity levels including in launch config. if properly oriented	
Light weight	
Ladder concept qualified at lunar gravity (LM)	
Positive control of direction and velocity	

The ladder/rail combination is intended primarily to provide short-range interlevel mobility for personnel. The vertical rail enables personnel carrying small packages in one hand to safely ascend or descend without the necessity of losing support contact by rung to rung hand transfer.

The high reliability and maintenance free design combined with

1.3 LADDER AND RAIL COMBINATION (CONTINUED)

relatively light weight and volume requirements make the ladder/rail a prime candidate for incorporation as backup for a powered inter-level mobility system.

The ladder/rail application as envisioned is limited by the length of the vertical rail between structural ties. This can be circumvented by utilizing a vertical rail with a modified U-shape permitting structural support as required without degrading the intended application.

Since both elements of the ladder/rail have been previously qualified on Gemini and Apollo, development time of the combination should be minimal.

1.4 PORTABLE HANDRAIL

Description

This concept as shown in Figure E-4 could be carried retracted, and when required, extended to wedge between walls, equipment racks, etc., as a temporary restraint device whenever needed. The user could place it under his arm or use it over his shoulder as a compression standing device. The ends may have bearing pads, suction cups or other attachments.

Weight: 1.5 lbs
Volume: 0.8 ft^3

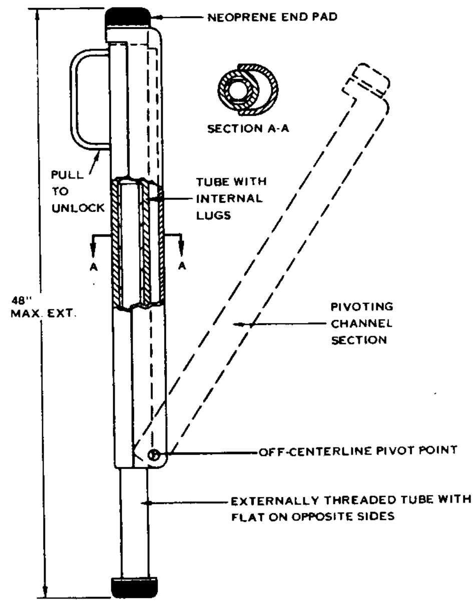


FIGURE E–4. PORTABLE HAND RAIL

1.4 PORTABLE HANDRAIL (CONTINUED)

Merits	Deficiencies
No electrical power required	Must be carried by user
May be incorporated without modification of vehicle design	Requires approximately parallel opposing surfaces for application
	Requires use of one hand/arm for restraint

The simplicity and freedom from maintenance should ensure a high reliability.

This restraint concept is primarily applicable to areas where permanently installed restraint systems are not feasible because of infrequent use. Use of three portable handrails would provide a portable leg rail restraint system.

1.5 LINEAR INDUCTION MOBILE HANDHOLD

Description

This concept shown in Figure E-5, employs a linear induction motor with a handhold attached that is propelled along a railing which provides electrical power, directional guidance, and also acts as the armature of the induction motor. A three position switch (forward, off, reverse) controls the motor, is integral with a handhold, and is operated with the thumb.

Weight: = 8 lbs + 0.8 lbs/ft
Volume: 0.6 ft^3 + 0.25 ft^3/ft

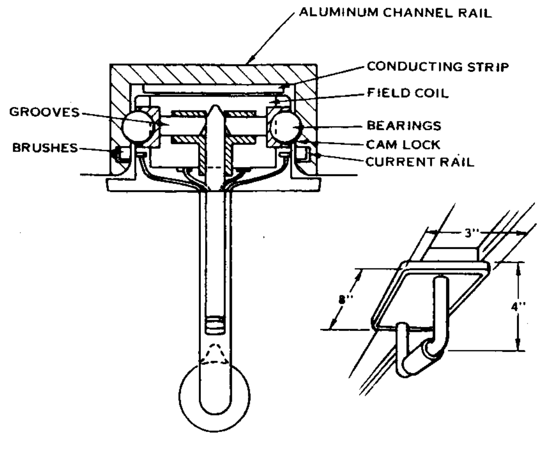


FIGURE E—5. LINEAR INDUCTION MOBIL HANDHOLD

1.5 LINEAR INDUCTION MOBILE HANDHOLD (CONTINUED)

Merits	Deficiencies
Positive control of direction and velocity	Electrical power required
Manual effort limited to holding on.	Requires one hand to operate
May be applied to equipment transport	Electromagnetic field generated requires RFI shielding of instrumentation and communication systems
Simplicity of operation	Flexibility limited by rail system
Limited to temporary restraint uses.	Simultaneous two way traffic requires parallel system
	Application should be incorporated in basic vehicle design

The linear induction mobile handhold is intended to provide inter-level, long range mobility in a zero gravity environment. Since the propulsion force of the handhold does not involve rotating parts, the system reliability would primarily be a function of the power source. It is expected that maintenance would be limited to brush and slide bearing replacement or refurbishment.

The major shortcoming is that common to all rail or trolley systems. Simultaneous two way traffic requires either parallel systems or a switching arrangement and would require a relatively large turning radius, or a separate unit for each new direction of travel.

As envisioned, handholds would be stowed at each boarding station in quantities designed to meet demands.

1.6 RIGID ROPE

Description

The rigid rope shown in Figure E-6, is essentially a tether with a controllable rigidity feature. In operation, one end would be attached to the spacecraft and the other end with a lever to the spacesuit of the astronaut. ACtuation of the lever in one direction causes the rigid rope to become very flexible, allowing the relative position of the astronaut and the work site to be changed with little effort. When the new position is obtained, actuation of the lever in the opposite direction causes the rigid rope to

1.6 RIGID ROPE (CONTINUED)

become taut and the astronaut is held firmly in place.

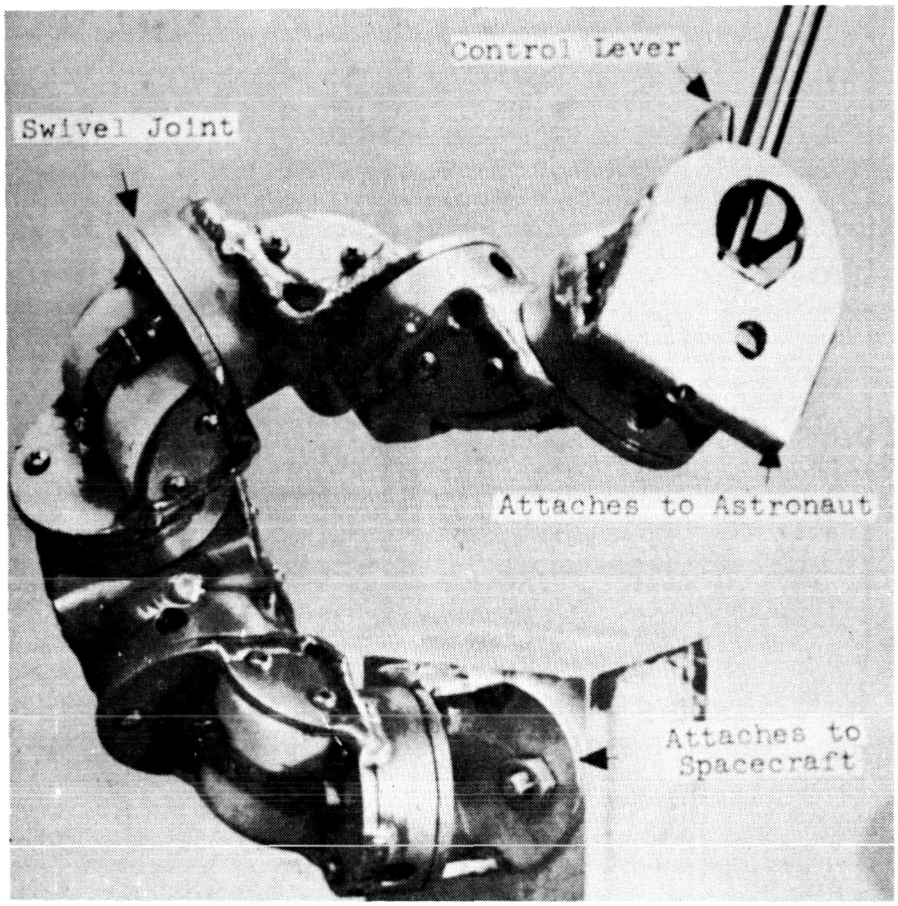


FIGURE E—6. RIGID ROPE

Along the length of the rigid rope there is a series of swivel joints, each having its plane of rotation located at right angles to those of the preceding and succeeding joints. Each joint mechanism is a set of ring gears attached to each side of the joint structure with a spur gear of the same pitch diameter mating with both. With the activation of the astronaut's control lever, the spur gear is moved in and out of mesh with both ring gears. When it is meshed with both ring gears, it acts as a fine-toothed spline and locks the joint; and when it is not, the joint rotates freely. Activation of the lever controls all the joints simultaneously. When the joints are locked, the rigid rope is rigid; and when they are unlocked, it is flexible.

1.6 Rigid Rope - Continued

Performance

A breadboard model was able to withstand 100 ft-lb (135.6 m-N) torques.

Advantages and Disadvantages

Unavailable.

1.7 Hand Model (Single-Pole) Electroadhesor

Description

The face of this adhesor, Figure E-7, is a single, insulated electrode. When the electrode is pressed against the adherend (e.g., a space vehicle's skin) and the power supply is turned on, opposite charges build up on the electrode and the adherend (the latter is used as a ground for the power supply). The attractive forces between these charges form a bond. The high voltage required for the process is provided by a mercury battery whose voltage has been stepped up by a dc to dc converter. In the steady state condition, current leakage occurs between the electrodes and the adherend. Thus, when the power switch is turned off, the charges begin to drain off. After several seconds, a slight bending force will remove the adhesor and the adseror is ready for reuse.

Battery voltage	8.4V
Supply voltage	1850V
Supply current	30 A
Theoretical battery life	

Performance

Laboratory tests have shown that the adhesor will withstand the following static loads: Tensile - 6 lb, Shear - 40 lb. A small mercury battery (Mallory TR-126T2) lasted 42 hours.

1.7 Performance - Continued

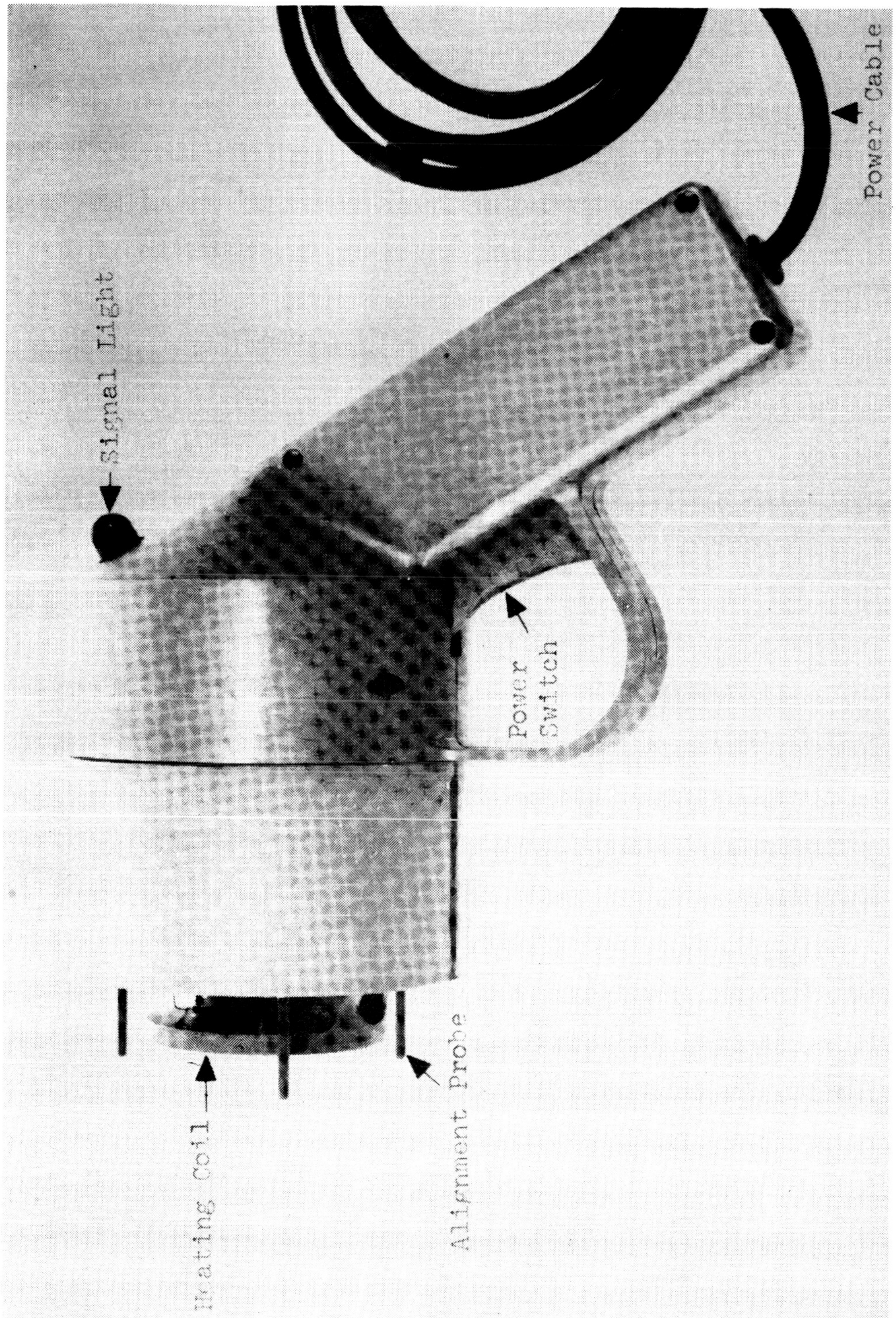


FIGURE E-7. HAND MODEL PROTOTYPE ELECTRO ADHESOR (SINGLE POLE)

1.7 HAND MODEL (SINGLE-POLE) ELECTROADHESOR (CONTINUED)

Advantages and Disadvantages

This adhesive tool can be used over and over again as long as its batteries last. However, it does not attach very well to a surface that is not smooth, clean and flat, and does not resist bending or peeling forces very well. A conducting surface is required.

1.8 FLEXIBLE (SINGLE-POLE) ELECTROADHESOR

Description

The face of this adhesor, Figure E-8, is a single, flexible, insulated electrode. The face is pressed against the adherend (e.g., a space vehicle's skin) and the power supply is turned on. In a few seconds, opposite charges build up on the electrode and the adherend (the latter is used as a ground for the power supply). The attractive forces between these charges form a bond. The high voltage required for the process is provided by a battery whose voltage has been stepped up by a dc to dc converter. In the steady state condition, a small electrical current flows between the electrodes and the adherend. Thus, when the power switch is turned off, the charges begin to drain off. After several seconds, a slight bending or peeling force will remove the adhesor and the adhesor is ready for reuse.

1.8 Flexible (Single-Pole) Electroadhesor - Continued

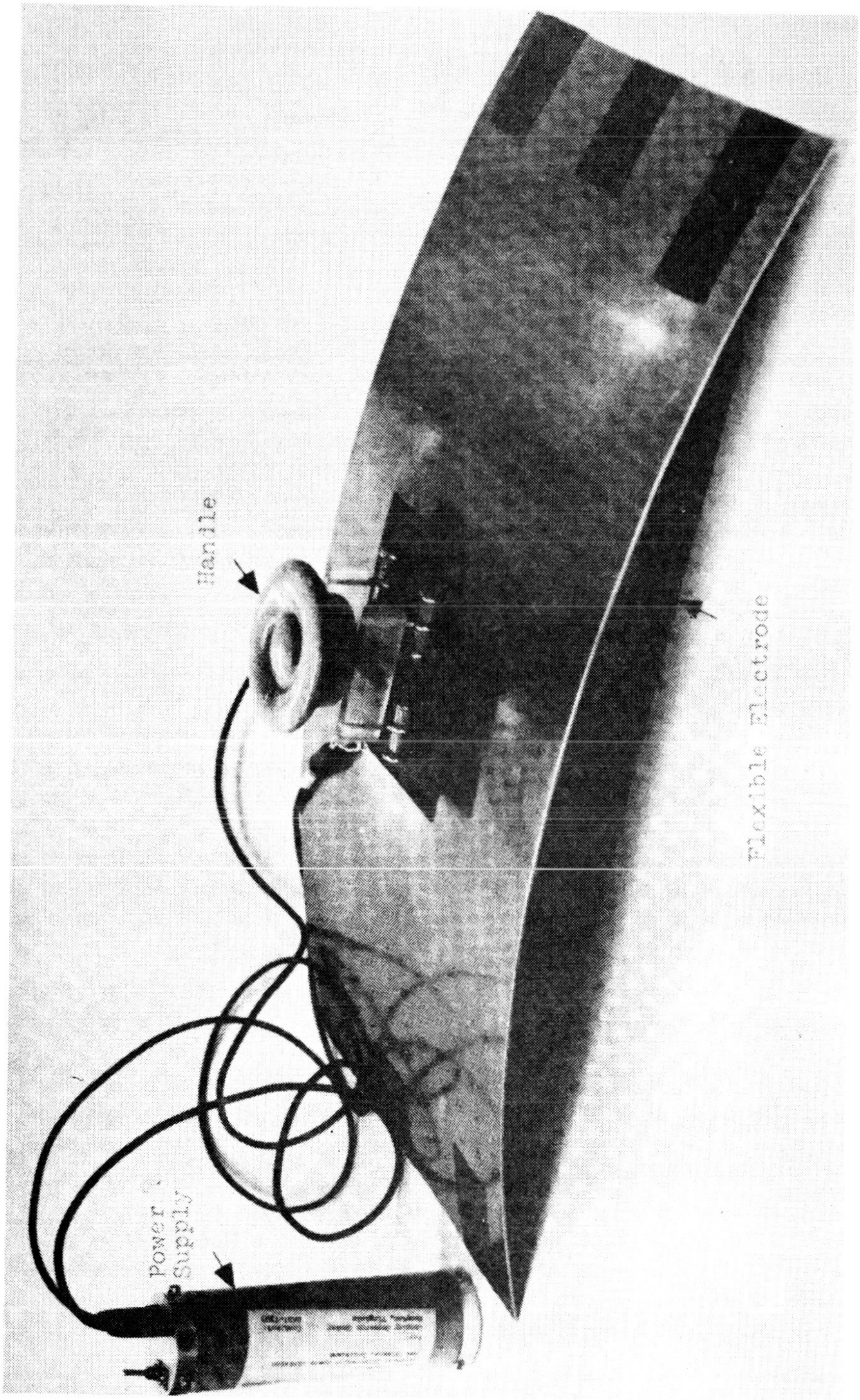


FIGURE E-8. FLEXIBLE PROTOTYPE ELECTROADHESOR (SINGLE POLE)

1.8 FLEXIBLE (SINGLE-POLE) ELECTROADHESOR (CONTINUED)

Length	1 in. (2.54 cm)
Diameter	4 in. (10.16 cm)
Battery voltage	8.4 V
Supply voltage	1850 V
Supply current	30 A
Theoretical battery life	30-40 hr

The power supply is contained in a small cylinder separate from the adhesor. Current is supplied to the adhesor through a pair of wires. This system permits remote operation of the adhesor.

Performance

Laboratory tests have shown that the adhesor will withstand the following static loads: Tensile - 2 lb, Shear - 1 lb. The small mercury battery lasted 40 hours.

Advantages and Disadvantages

This adhesive tool can be used over and over again as long as its batteries last and it is designed to adhere better to curved surfaces than the hand model prototype (single-pole) and the hand model (two-pole) electroadhesors. The flexible prototype has the additional capacity of remote control. In order for the flexible prototype to attach, the adherend must be smooth and clean and must be able to conduct electricity. The flexible prototype does not resist bending or peeling forces very well.

1.9 HAND MODEL PROTOTYPE (TWO-POLE) ELECTROADHESOR

Description

The adhesor, shown in Figure E-9, is pressed against a clean, smooth, flat surface, the adherend. The face of the adhesor consists of two electrodes insulated from the adherend by a die-electric. When power is turned on, a high charge density is created within the electrodes which causes the formation of image charges (of opposite polarity) on the surface of the adhering material. The attractive forces between these charges effect the bond. The high voltage required for this process is provided by a mercury battery whose potential has been stepped up by a dc to dc converter. In the steady state, current leakage occurs between the electrodes and the adherend; thus, when the power is turned

1.9 HAND MODEL PROTOTYPE (TWO-POLE) ELECTROADHESOR (CONTINUED)

off, the charges begin to dissipate. After several seconds a slight bending force will remove the adhesor and it is ready for reuse.

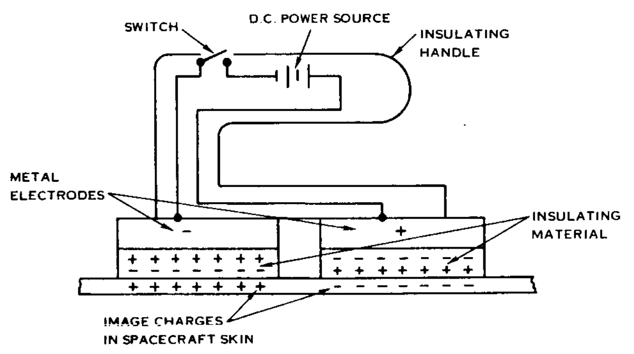


FIGURE E-9. HAND MODEL PROTOTYPE (TWO POLE)

Battery voltage	8.4 V
Supply voltage	1850 V
Supply current	30 A
Theoretical battery life	30-40 hr

Performance

Laboratory tests have shown that the adhesor will withstand these static forces with an applied potential of 1850 volts; Tensile - 3 lb, Shear - 18 lb. The small mercury battery lasted 27 hours.

Advantages and Disadvantages

This adhesive tool can be used over and over again as long as the batteries last. However, it does not attach very well to a surface that is not smooth, clean, and flat, and does not resist bending or peeling forces very well. A conducting surface is required.

2.0 TORSO RESTRAINT DEVICES

2.1 PELVIC RESTRAINT

Description

The pelvic restraint shown in Figure E-10, provides good suited and shirt sleeve crew station/work area restraint capability for a crewman, without the requirement of continuous effort to use same. The unit provides for position adjustments in all task reference planes, by use of three (3) manual controls as shown. Personnel restraint, within the device is via a simple lap belt. The unit requires a structural interface at each crew station (i.e.; a rail or tube), which limits general applicability.

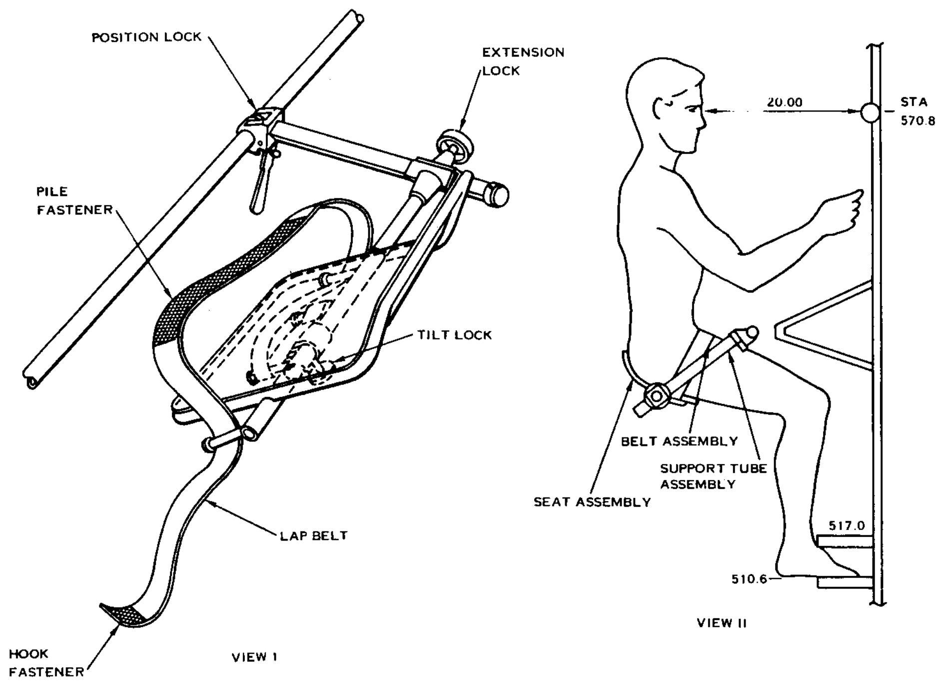


FIGURE E-10. FLIGHT CREW PELVIC RESTRAINTS

Merits

- No electrical power
- Durable
- Low Maintenance
- Applicable to all levels of gravity
- Positive position control
- Good for long term crew station restraint

Deficiencies

- Limits mobility and reach to arms length
- Requires use of both hands to ingress/egress the unit
- Structural interface with vehicle; should be incorporated in vehicle design.

2.2 INFLATABLE MID TORSO RESTRAINT

Description

The restraint shown in Figure E-11 consists of a spring steel frame on which is mounted an inflatable form. By spreading the restraint frame, the person positions his mid section within the restraint. The inflatable bladder has the ability to provide pressure for force resistance while still maintaining the ability to adapt to different body shapes and proportions. By anchoring the person's hips and buttocks, the restraint allows freedom of legs, feet, arms, head and torso.

Weight: 3.2 lbs.
Volume: 0.4 ft^3

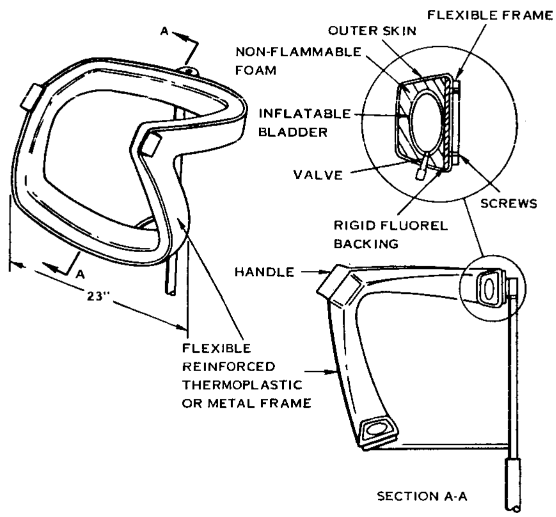


FIGURE E-11. INFLATABLE MID-TORSO RESTRAINT

Testing

None (New Concept)

Merits	Deficiencies
Uses no electrical power	Requires means of inflation
Broad applicability	
Usable in all gravity levels	
Simple	
Light weight	
Provides familiar pressure of chair	
Can be made portable	

2.2 INFLATABLE MID TORSO RESTRAINT (CONTINUED)

The simplicity and maintenance-free design of the Inflatable Mid Body Restraint should result in a reliable restraint applicable in a variety of "sitting" situations, i.e., console operation, laboratory, etc.

2.3 RIGID WAIST TETHER

Description

This concept, shown in Figure E-12, consists of a telescoping, rigid tube affixed to the waist tether belt with a slide similar to that of a D-ring. The rigid tube has a ball-joint on the slide, permitting the tether to swivel at the user's waist. Once extended to the length desired, the collect clamp can be tightened by use of the nut, or the tension spring can be used to apply the required forces. This tether can be used in pairs with swiveling pip-pins which can be locked into receptacles anywhere in the spacecraft, or a rigid pin can be used to attach one tether to the slide assembly as a mobility aid.

Weight: 7.5 lbs.
Volume: 0.8 ft^3

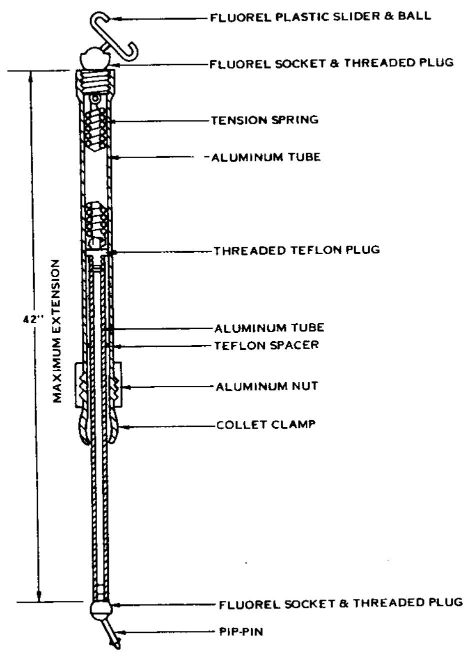


FIGURE E–12. RIGID WAIST TETHER

2.3 RÍGID WAIST TETHER (CONTINUED)

Merits	Deficiencies
Uses no electrical power	Requires means of inflation
Broad Applicability	
Usable in all gravity levels	
Simple	
Light Weight	
Provides familiar pressure of chair	
Can be made portable	

2.4 SLIDE ASSEMBLY - RIGID TETHER

Description

Figure E13 shows the slide assembly intended for use with the Telescoping Rigid Tether and the Waist Tether Belt. The slide is attached to a standard handrail via spring loaded rollers and employs a tether attach point which is also spring loaded. The tether attach arm (pressure arm) applies a downward force to the user through the rigid tether, affording him the necessary traction to propel himself by walking. This slide, with minor modification, could be arranged to accept a pallet for transporting equipment.

Weight: 7.5 lbs.
Volume: 0.8 ft^3

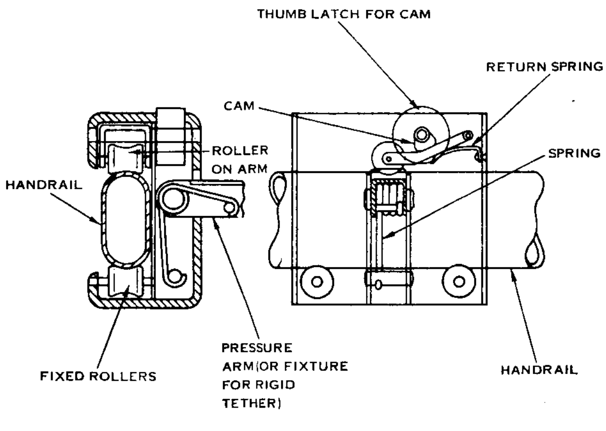


FIGURE E–13. SLIDE ASSEMBLY RIGID TETHER

2.4 SLIDE ASSEMBLY - RIGID TETHER (CONTINUED)

Merits	Deficiencies
Uses no electrical power	Requires means of inflation
Broad applicability	
Usable in all gravity levels	
Simple	
Light Weight	
Provides familiar pressure of chair	
Can be made portable	

2.5 BELT - WAIST TETHER

Description

Figure E-14 shows the belt and attachment for waist tethers. The attachment pictured is a D-ring and slide intended for use with the flexible tethers. The slide is just wide enough to prevent twisting on the belt. The user can position the D-ring slide at any point on the belt, thereby giving himself extra body twisting ability. This belt can be used for either the flexible or rigid waist tethers.

The Rigid Waist Tether employs a rigid tether connected to a handrail mounted slide and a belt worn by the user. The slide assembly/rigid tether connection is spring loaded to exert a downward force on the tether providing a gravity substitute force enabling near normal walking by the user.

Weight: 7.5 lbs.
Volume: 0.8 ft^3

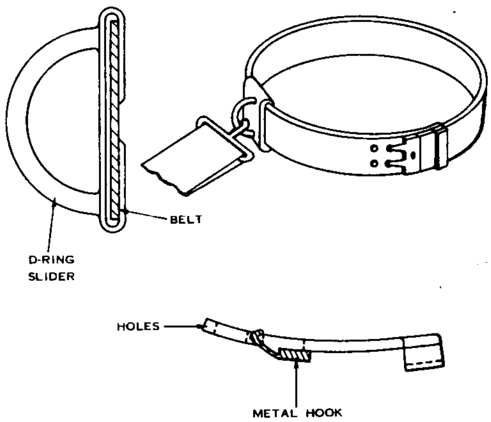


FIGURE E-14. WAIST TETHER BELT

2.5 BELT - WAIST TETHER (CONTINUED)

Merits	Deficiencies
No electrical power required	Mobility range limited to handrail system
Restraint system provides gravity substitute force enabling hands free mobility	Simultaneous two way traffic requires parallel systems
Can be used for transporting equipment	Maintenance required
Removable from handrail for stowage	Tolerance critical to prevent binding

The simplicity of the design combined with periodic maintenance and inspection should ensure a reliable system.

Application of the Rigid Tether is intended for zero gravity work stations where limited mobility is required, or for hands-free mobility in long passageways. In instances where hands-free mobility is not required, grasping the rigid tether with one or both hands will provide the user with the capability of compression walking without having to physically complete the belt/tether connection.

Rigid tethers can be used in zero gravity situations where it is necessary to maintain a location and position not allowing use of the flexible tether.

2.6 FLEXIBLE WAIST TETHERS

Description

This restraint system, shown in Figure E-15, consists of the waist tether bolt, with tow D-ring slides worn by the user, and two tethers which attach to the D-rings via, spring slips. The other end of the tethers can be attached to fixed rings on the interfacing work areas. By adjusting the tethers to provide a force component downward, the user can restrain himself for successful performance of many tasks.

Weight: 2.0 lbs.
Volume: 0.2 ft^3

2.6 FLEXIBLE WAIST TETHERS (CONTINUED)

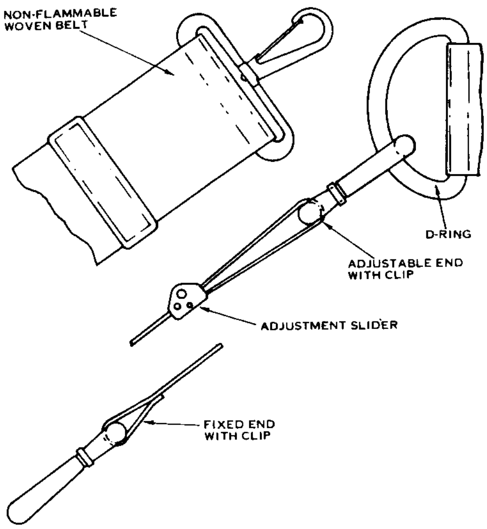


FIGURE E–15. FLEXIBLE WAIST TETHER

Testing

Evaluated on MOL Program; A/C Flt. tested

Merits	Deficiencies
Requires no electrical power	Requires structural attach fittings and personnel harness or belt attachment
Applicable for tasks requiring exertion of high torques	Mobility limited by tether length
Minimizes effort required for body control	Usually requires both hands for connect/disconnect
Broad variety of configurations adaptable to many applications	
Superior mobility when used with foot restraint	

Waist tethers developed and qualified on Gemini EVA were of the flexible tether type, limiting movement within an envelope determined by tether length, or providing a gravity substitute force by interaction of the users legs to place the tethers in tension.

2.7 LEG RAIL RESTRAINT

Description

The restraint apparatus shown in Figure E-16, consists of two rigid rails used in conjunction with the outermost edge of control panels. With toes hooked under the bottom rail and knees over the top rail, the crew member can obtain three point restraint by employing a slight body pressure on the edge of the console or work station.

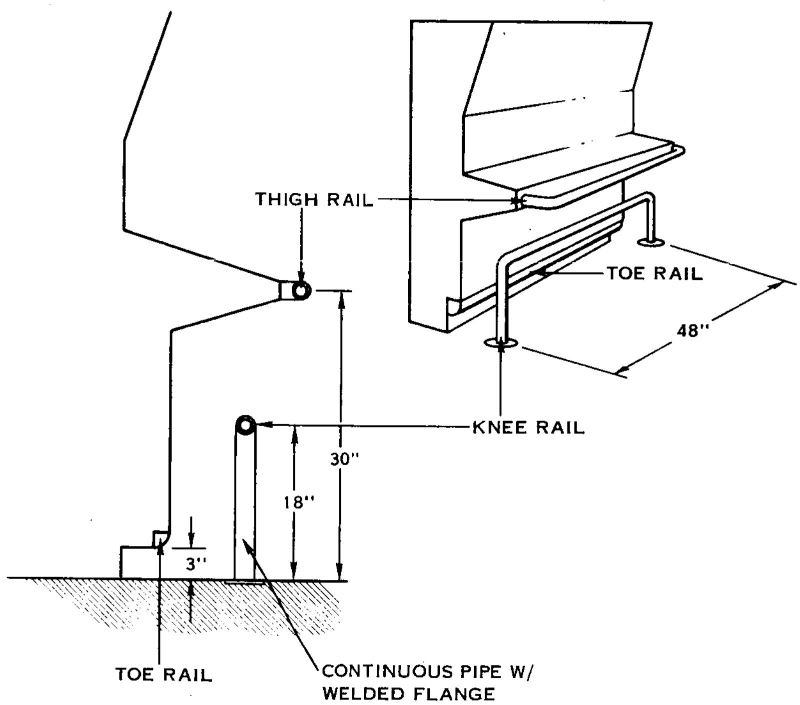


FIGURE E—16. LEG RAIL RESTRAINT

Weight: 1.0 lbs/ft
Volume: 0.2 ft^3/ft

Testing

None (New Concept)

2.7 LEG RAIL CONSTRAINT (CONTINUED)

Merits	Deficiencies
Requires no electrical power	Not usable in artificial gravity environment
Does not restrict movement of trunk, arms or head	May cause pressure points after prolonged use
Light weight	Not a "natural" restraint position in which to work
Simple design	Requires continuous effort to stay in restraint, particularly in shirt sleeve mode.
Applicable for zero gravity "sitting"	

The simplicity of this restraint system results in a reliable maintenance-free design applicable in zero gravity "sitting" situations.

Modification of the concept by deleting approximately an 8-inch section in the middle of the knee rail would enhance applicability for dressing or body cleaning in zero gravity environments.

The toe restraint may be incorporated into the console or work bench and produce another variation of this system.

2.8 ASTRONAUT BOOM ATTACHMENT SYSTEM

Description

The astronaut boom attachment system, shown in Figure E-17, is a backpack with three extendable booms. The booms can be extended or retracted individually or together. All the attachment system controls are mounted close to the right hip. The booms are standard STEM (Storable Tubular Extendable Member) tubes made from stainless steel strips that are pretensioned to form tubing.

When the booms are in the retracted position, they are flattened and rolled onto a spool. When extension is necessary, operation of the extension crank permits the inherent strain energy of the pretensioned steel to unroll the spool under the control of a special brake. As the stem material rolls off the spool, it automatically curls into a tube. Operation of the crank in the opposite direction opens the tube as it enters the spool container, flattens it and rerolls it onto the spool. An adhesor system is required at the end of each boom to form a firm attachment to the ship.

2.8 Astronaut Boom Attachment System - Continued

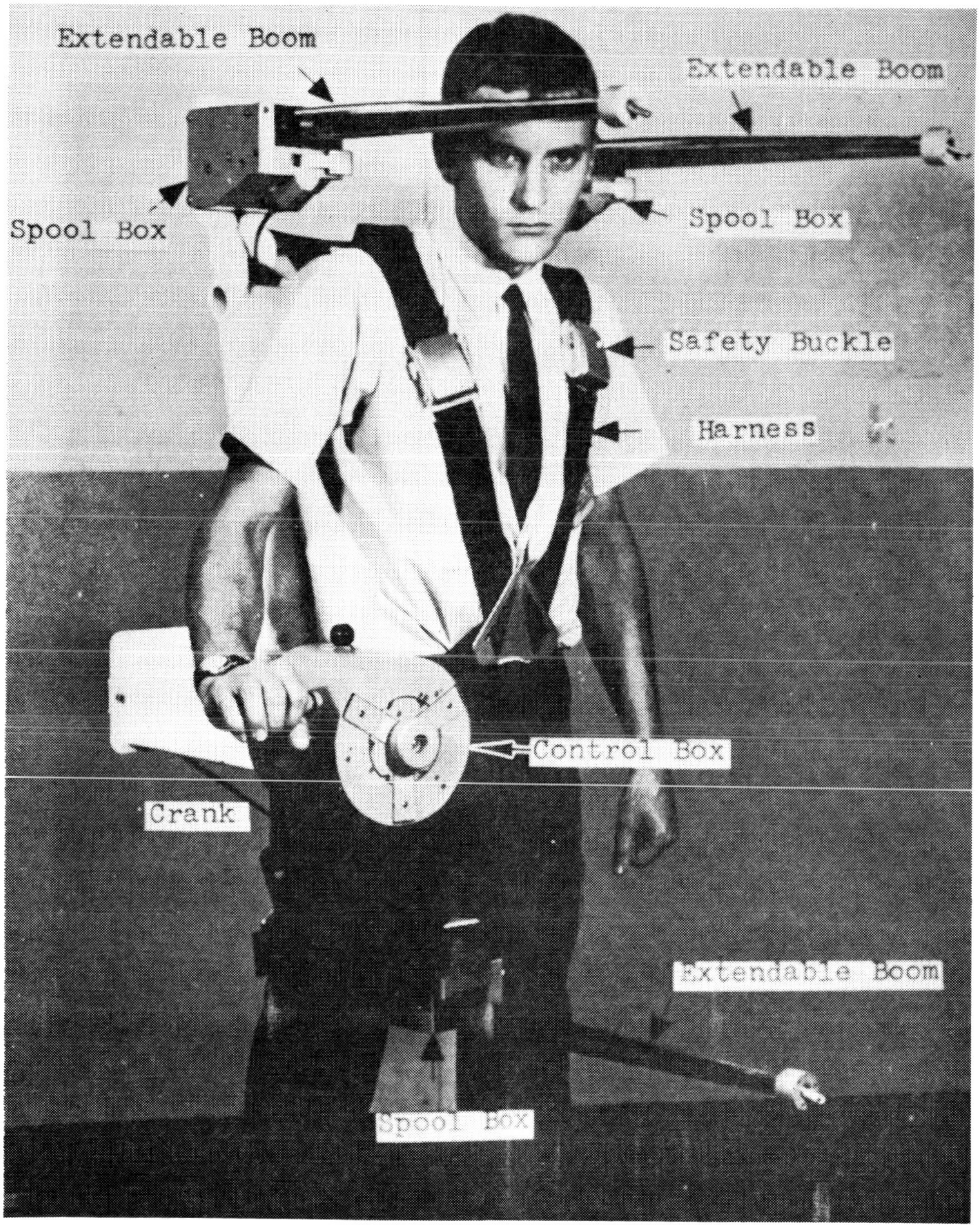


FIGURE E-17. ASTRONAUT BOOM ATTACHMENT SYSTEM

2.8 ASTRONAUT BOOM ATTACHMENT SYSTEM (CONTINUED)

Frame:

Height	36 in. (91.4 cm)
Width	20 in. (50.8 cm)
Thickness	1.5 in. (3.81 cm)

Control Box:

Length	18 in. (45.7 cm)
Diameter	6.5 in. (16.5 cm)

Spool Box:

Length	9 in. (22.8 cm)
Height	5 in. (12.7 cm)
Width	4 in. (10.2 cm)

Boom:

Sheet width	3 in. (7.6 cm)
Sheet thickness	0.004 in. (0.01 cm)
Boom nominal diameter	.0.75 in. (1.9 cm)

Performance

The system has been tested in a 5 degree-of-freedom simulator. It withstood a 45 ft-lb torque at a boom extension of 2.75 ft.

Advantages and Disadvantages

The torques applied with a cranking motion were found to create an undesirable amount of instability. It was recommended that future systems be motorized. It was analytically determined that a new Bi-STEM boom principle will produce stronger tubes and increase the systems reaction absorbing capability fourfold.

2.9 POSITIONING TOOL (MAINTENANCE TETHER SYSTEM)

Description

The positioning tool, shown in Figure E-18, has five major parts: the astronaut belt, two quick release Ball-Lock Pins and two restraint assemblies. The belt is worn around the astronaut's waist. A restraint assembly is attached to each connect coupling on the outer end of the telescoping tubes of each restraint assembly. It holds an attaching device which is used to anchor the positioning tool and thus the astronaut to a space vehicle structure. A number of attaching devices have been developed for various shaped structures.

2.9 Positioning Tool (Maintenance Tether System) - Continued

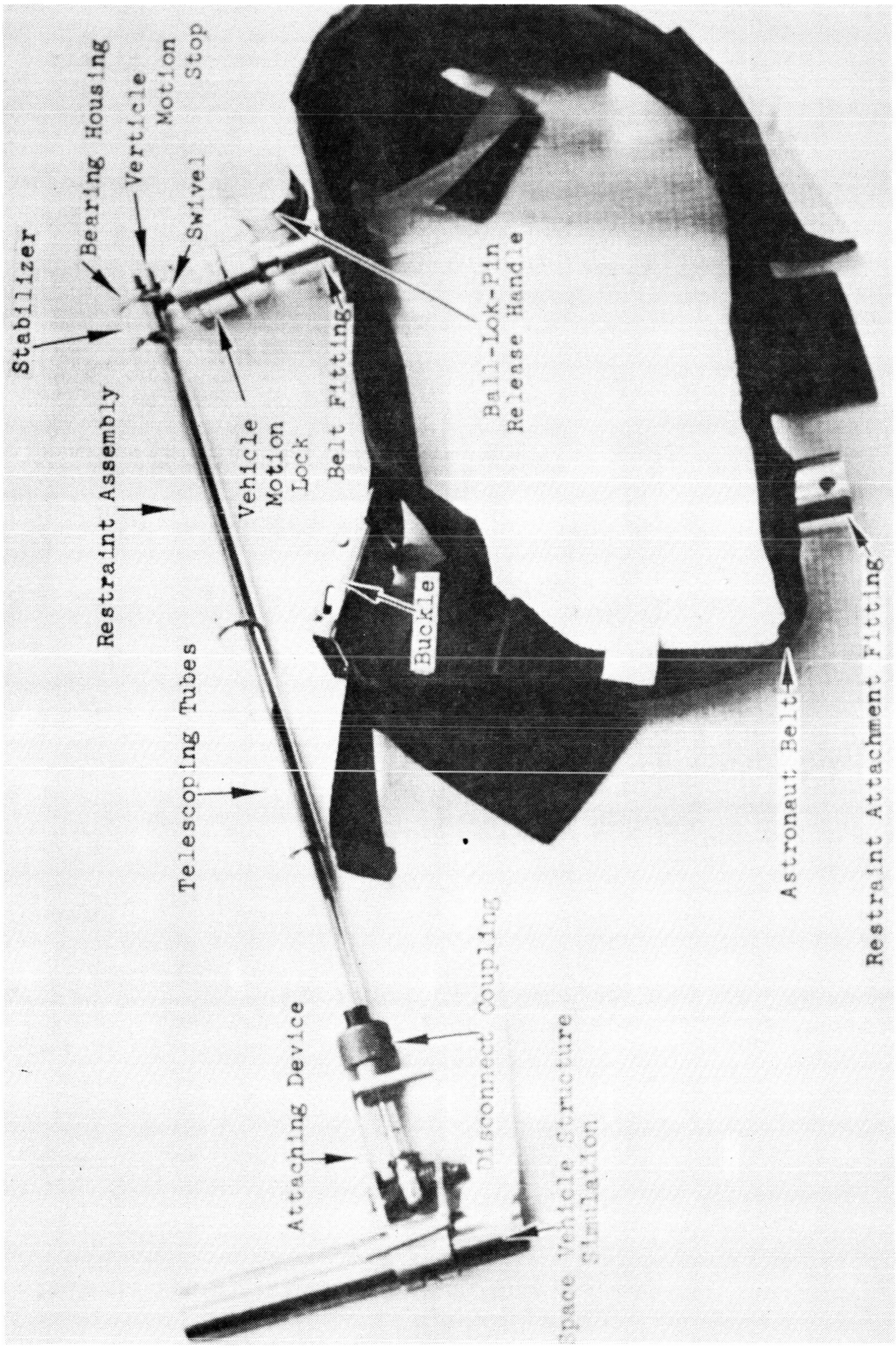


FIGURE E–18. POSITIONING TOOL

2.9 POSITIONING TOOL (MAINTENANCE TETHER SYSTEM) (CONTINUED)

Several adjustment features allow the astronaut to adjust and maintain his position with respect to the structure attachment points. The telescoping tubes of each of the restraint assemblies may be locked at any position between its collapsed and extended positions by simply rotating each of the extended sections a slight amount, thus activating an internal locking mechanism. Thus the astronaut is given a wide adjustment in his distance from the structure. The telescoping tubes may also be rotated through 360° (6.28 rad) about the longitudinal axis of the belt and restraint attachment fittings and locked in any position with the rotation of the vertical motion lock on the same axis. In addition, the telescoping tubes may also be pivoted in any direction or in circular motion about the center of the spherical ball bearing of the swivel. The amount of motion in any direction is limited by the design of the swivel, the stabilizer and the vertical motion stop aft of the swivel. The spring-loaded stabilizer presses firmly against the bearing housing and resists displacement of the tubes from the center position. Thus the astronaut must apply a small force in the direction of the desired motion in order to cause the tubes to pivot about the ball bearing. Finally, the quick disconnect coupling which holds the structure attaching device may be freely rotated through 360° (6.28 rad) about the longitudinal axis of the tubes. In an emergency, the astronaut can disconnect himself from the vehicle structure in several ways: He can quickly unbuckle his belt which uses the ends of an automobile safety belt for buckling; he can activate the button release handles on the quick release Ball-Lok-Pins which would uncouple the restraint assembly from the belt; or, finally, he can disconnect the attaching devices from the quick disconnect couplings.

Performance

A fully extended tube assembly will not fail as a column under a compressive force of 200 lb (890 N).

Advantages and Disadvantages

Unavailable

2.10 SERPENTUATOR (SERPENTINE ACTUATOR)

Description

The serpentuator, shown in Figure E-19, consists of a series of cylindrical links separated by joints driven by electric motors so that they may bend as much as by joints driven by electric motors so that they may bend as much as 45° (0.785 rad) in one direction. All these joints bend in the same direction in the plane. The base end of the serpentuator is attached firmly to the ship through a series of motorized joints that allow the serpentuator to roll as much as +200° (3.49 rad) and yaw as much as +120° (209 rad). Attachments can be placed at the tip end to support an astronaut and/or cargo. Three motorized joints separate the last link and the tip attachment, and give the attachment yaw, pitch and roll capabilities. The serpentuator has quick disconnect capabilities at both the base and tip ends, and it can be operated by controls at either end. When not in use the serpentuator can be coiled about a coil rack.

Number of links	8
Link length	60.5 in. (154. cm)
Link diameter	4.5 in. (11.4 cm)

2.10 Serpentuator (Serpentine Actuator) - Continued

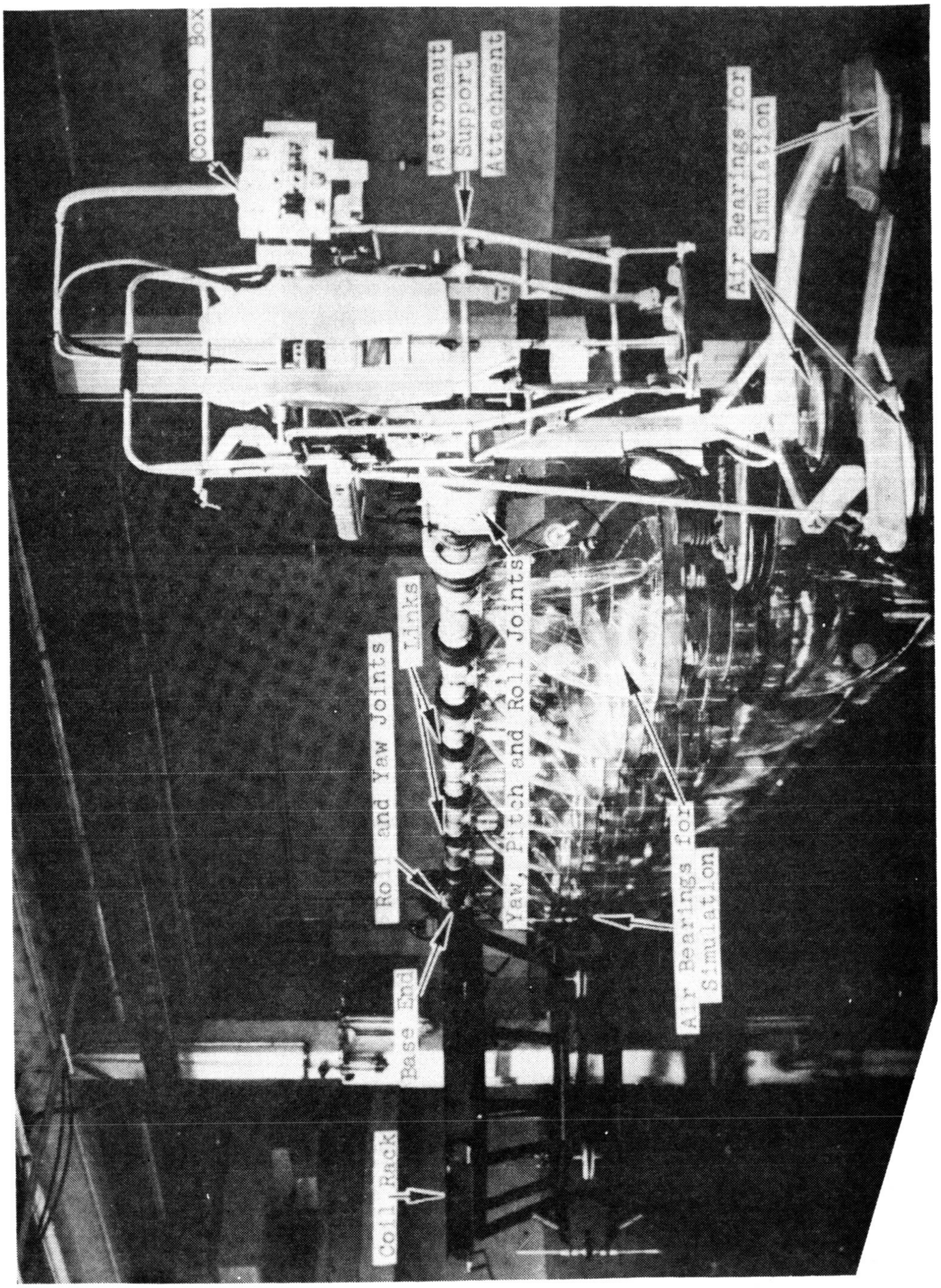


FIGURE E-19. SERPENTHATOR

2.10 SERPENTUATOR (SERPENTINE ACTUATOR) (CONTINUED)

Performance

It is projected that the serpentuator should be able to withstand a free end force of 6 lb (26.7 N) with a mechanical design safety factor of 1.5 and an impact load factor of 3.

Advantages and Disadvantages

Unavailable

3.0 FOOT/LOWER LEG RESTRAINT DEVICES

3.1 FIXED FOOT RESTRAINT (DUTCH SHOES)

Description

The diagram in Figure E-20 shows a top view of two rigid shoe restraints which can be fixed to any surface. The user restrains himself by inserting his feet into the restraints and rotating the toes outward until both toes and heels are held under the rim of each restraint. He can then resist work forces through reaction points at his heels and toes.

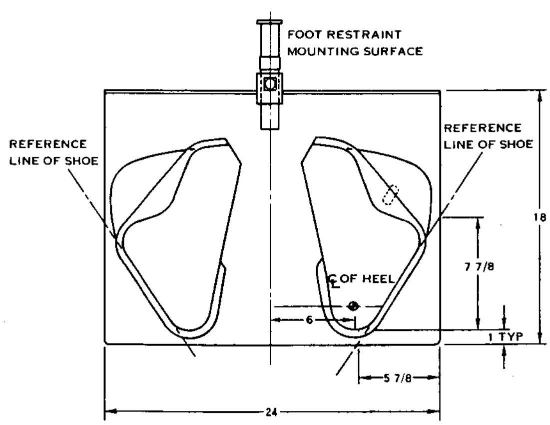


FIGURE E–20. FIXED FOOT RESTRAINT (DUTCH SHOES)

Weight 12.1 lbs
Volume 0.7 ft^3

3.1 FIXED FOOT RESTRAINT (DUTCH SHOES)

Merits

- Rapid entry and exit from restraint
- Simplicity
- Qualified on Gemini and Apollo
- Excellent for work stations requiring high torque expenditure

Deficiencies

- Structural interface with vehicle
- Requires conscious effort to retain restraint
- Handhold provision desirable for restraint entry
- Requires degree of personalized sizing

The Dutch Shoe restraint was fully developed and qualified for use on Gemini and Apollo flights. It was rated by the pilots as the best overall restraint for localized work in zero gravity. This restraint can be used very effectively in conjunction with handholds or waist tethers. It may be permanently fixed in required locations or made portable, to be fastened in place only when required.

3.2 ASTROGRID SHOE RESTRAINT

Description

The restraint system, shown in Figure E-21, consists of a floor grid surface of triangular holes in a hexagonal array. Shoes are provided with interfacing, positive triangular shapes or cams which are mounted off the mid-sole of the shoe. The system acts as both a restraint and a mobility device. The person inserts the cam of the shoe into a triangular hole in the floor grating and by twisting the shoe a given amount, it becomes securely fastened to the grating.

3.2 ASTROGRID SHOE RESTRAINT (CONTINUED)

The hexagonal array of triangular floor openings allows for the widest possible directions of movement.

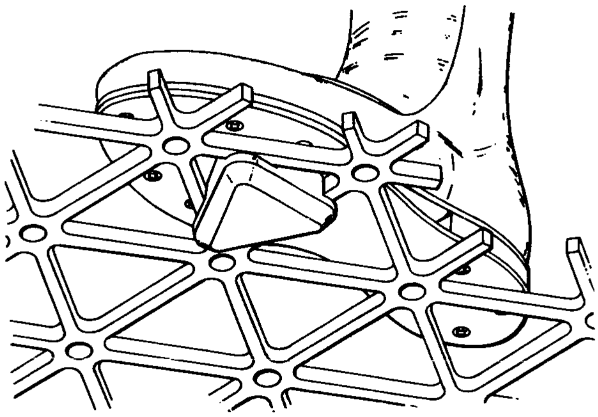


FIGURE E–21. ASTROGRID SHOE RESTRAINT

Testing

Neutral Buoyancy KC-135 Zero Gravity Flights (selected as primary IV restraint for Skylab).

Merits

- Positive restraint - excellent for activities requiring high torque
- Provides short range mobility at/between work stations
- Retention of restraint without conscious effort
- Foot restraint does not impede mobility or dexterity of rest of body

Deficiencies

- Footwear can be worn only in zero gravity
- Triangular grid surfaces are integral part of restraint
- Individual footwear required for proper fit and hygiene
- Handholds should be provided for temporary restraint while engaging restraint system
- Requires good ankle mobility for suited applications

3.3 LOWER LEG RESTRAINT

Description

The unit, shown in Figure E-22, provides effective restraint for both shirtsleeve and suited modes by holding the knees and lower legs against a portion of the crew station structure. The crewman lodges his legs between the restraint unit and the vehicle structure with the assistance of handholds, etc. The unit is portable, and it can be installed with pip-pins. The height of the restraint can also be adjusted to accommodate suit and shirtsleeve dimensional variations. The unit can swivel through 360°, however, accessibility at the crew station is limited to arms reach.

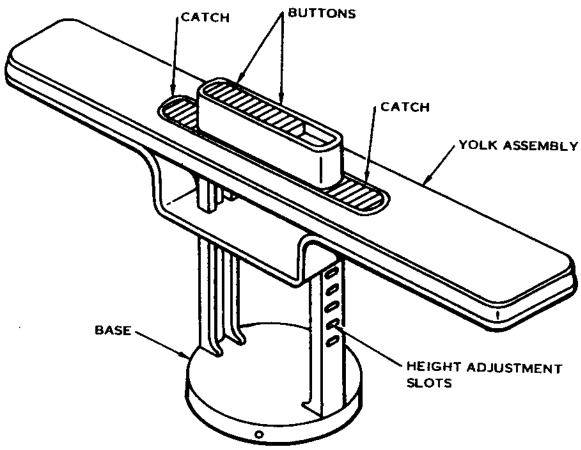


FIGURE E-22. LOWER LEG RESTRAINT

Merits

- No electrical power
- Low maintenance
- Zero -"g" restraint only
- Short duration restraint
- Simple

Deficiencies

- May result in pressure points after long exposure
- Mobility limited to arms length
- A crew station panel clear of obstructions is required because of direct suit contact

3.4 FOOT RESTRAINT PLATFORM

The unit, shown in Figure E-23, contains two (2) foot pads with an adjustable padded pressure bar which is compressed across the top of the foot to retain same once it is inserted. The pressure bar can be adjusted vertically to accommodate a large range of shirtsleeved (dust cover shoe) and suited crewmen. The unit is portable, and requires only two (2) female fittings at the crew station for structural interface.

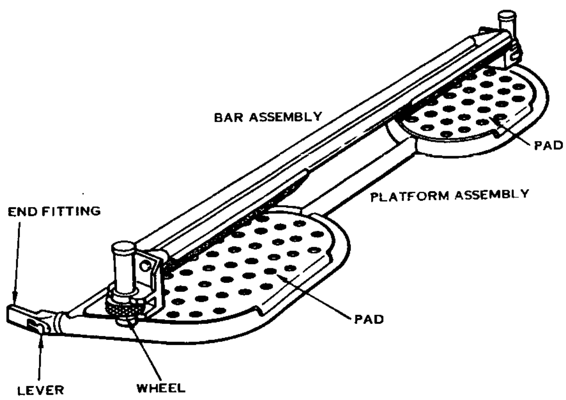


FIGURE E—23. FOOT RESTRAINT PLATFORM

Merit	Deficiencies
• No electrical power	• Continuous effort required to maintain foot in restraint
• Simple to use	• Requires temporary restraint for installation and ingress
• Short duration use	

3.5 MAGNETIC "SHUFFLER" SHOE

Description

This concept, shown in Figure E-24, uses a shuffling technique-sliding one foot forward on a low coefficient of friction surface, maintaining constant contact with the floor. The propelling force originates from the high coefficient of friction surface in the heel area of the foot. The low coefficient of friction and high coefficient of friction materials are Teflon and Viton, respectively. The use of these materials in conjunction with the distributed attractive force not only provides the user with stability in shuffling and performing tasks, but also allows easy separation from the floor when free float is desired.

The shoe consists of a fabric upper part in a loafer design, with the magnetics imbedded in the sole and heel portions. A strap with a D-ring arrangement is attached to the shoe and routed over the instep to permit lifting the heel magnet from the floor.

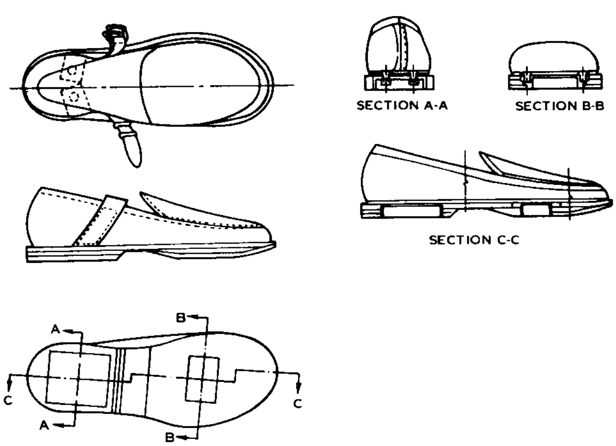


FIGURE E—24. MAGNETIC 'SHUFFLER' SHOE

Weight 4.5 lbs/pair
Volume 0.03 Ft^3/pair

3.5 MAGNETIC "SHUFFLER" SHOE (CONTINUED)

Testing

Ground tested in neutral buoyancy tank and on air bearing zero gravity simulator. Flight evaluation in KC-135 zero gravity.

Merits

- No electrical power requirements
- Footwear can be worn in artificial gravity environment and serve as primary footgear

- Soft iron floor is an integral part of restraint system - excessive weight penalty for other than limited application
- Incorporation of this concept would require shielding of instrumentation and displays, complicating construction pre-launch and onboard checkout of vehicle
- Requires individual issue to each crewman

The magnetic shoe (shuffler) developed under Contract NAS 9-9336 would require periodic spray application of Teflon to the sliding surface of the footwear. Initial test evaluation on KC-135 zero gravity flights determined:

- In the opinion of the test subject, the "shuffling" method of walking was quite unnatural and required attention on his part.
- Practical application would be limited to work stations which require limited amount of translation by the operator.

The use of this concept would also be limited by the high weight penalty imposed by the requirement for iron flooring.

This concept, if it is to be considered at any time, requires more development to overcome some inherent problems such as fit to crewmen, and the attractive force of the magnets.

3.6 SUCTION SHOES

Description

This concept, shown in Figure E-25, incorporates suction diaphragms on the soles of shoes. The suction diaphragms are activated by placing the shoe on a smooth surface and twisting the foot which operates a large-pitch screw mechanism to draw the vacuum between the diaphragm and the floor. As the shoe twists, the suction cup remains in a fixed position on the floor. By returning the foot to the normal position, the vacuum can be eliminated.

This concept is primarily intended as a short duration restraint system with possible use as a short range mobility aid.

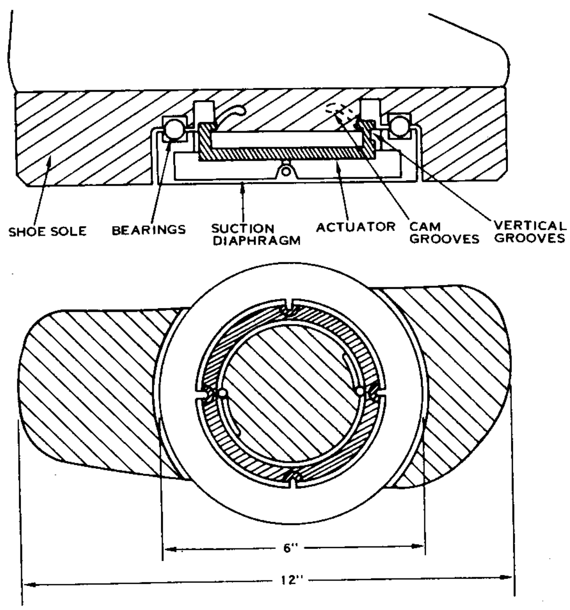


FIGURE E-25. SUCTION SHOES

Weight 2.0 lbs/pair
Volume 0.5 Ft^3/pair

3.6 SUCTION SHOES (CONTINUED)

Testing

None (New Concept)

Merits

- Uses no electrical power
- Simple to use
- Restraining force derived from existing ambient pressure
- Broad applicability
- Primarily intended for short range mobility or restraint in zero gravity - may be worn in artificial gravity environment
- May be added at any time
- Restraint of each foot provides redundancy

Deficiencies

- Requires smooth, clean surface for proper function
- Restraint duration dependent on leakage rate
- Restraint loss occurs without warning
- Maintenance required
- Footwear equipment requires individual assignment for fit and hygiene
- Requires temporary restraint for initial engagement
- Training required for proper foot movement
- Not applicable for EVA

Reliability of the suction shoe would be inherently good based on mechanism simplicity. Maintenance would be limited to periodic suction diaphragm replacement. Concept development is estimated at six months to one year.

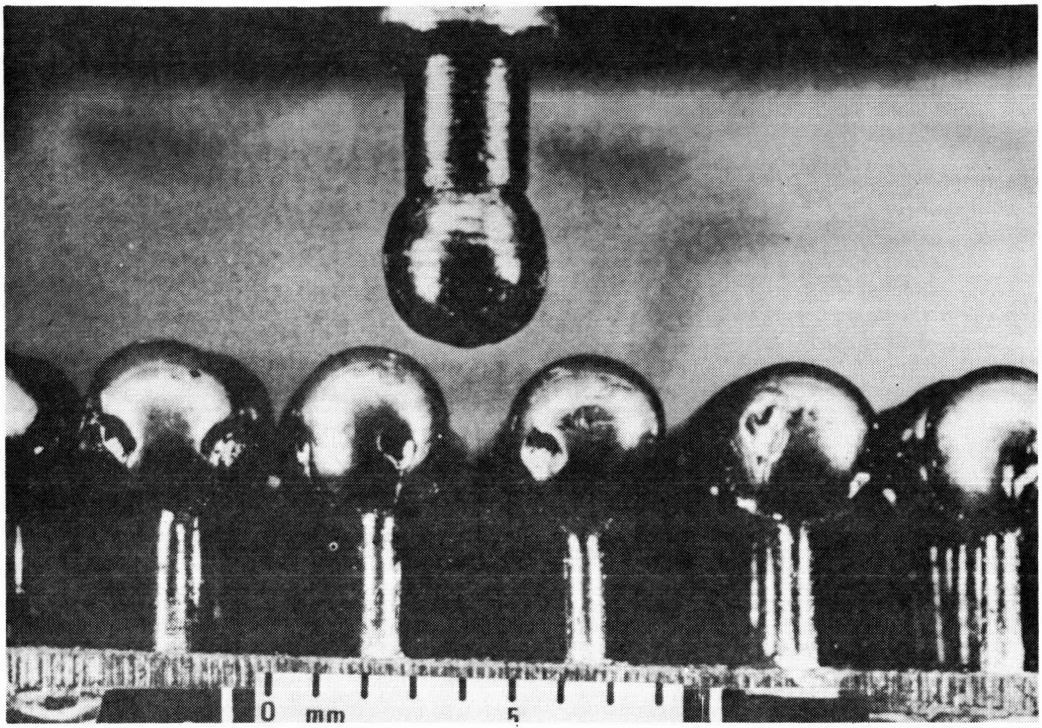
Requirements for floor smoothness compatible with use of suction shoes must be established by test. Smoothness requirements would determine the cost penalty incurred by implementation of this concept. A weight penalty is not anticipated.

3.7 ZERO GRAVITY SURFACE AND INTERLOCKING STRUCTURE

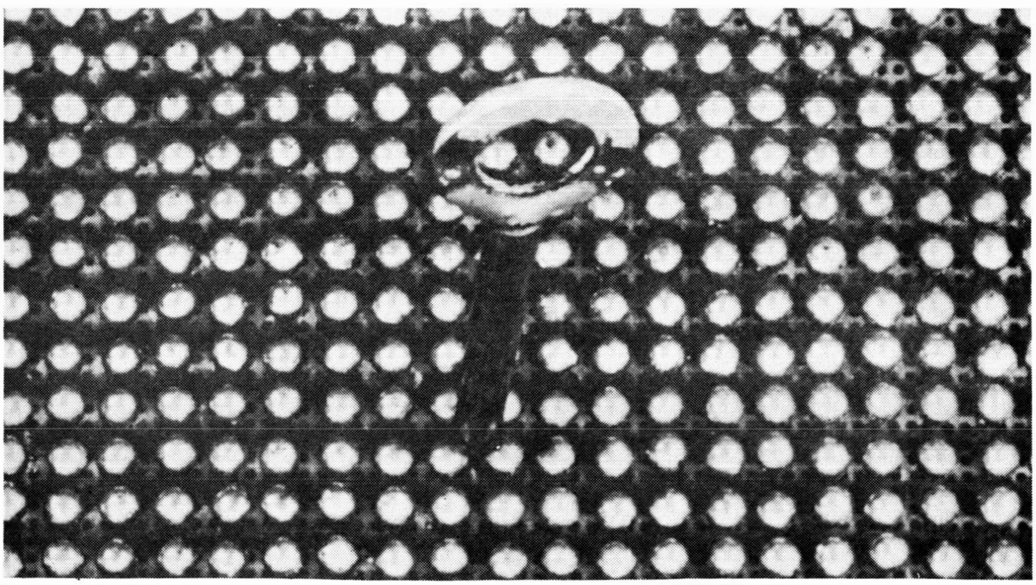
Description

The system, shown in Figure E-26, consists of a primary surface referred to as the zero-gravity surface and a secondary surface

3.7 Zero-Gravity Surface and Interlocking - Continued



A — A SAMPLE SPHERE OF AN INTERLOCKING STRUCTURE POISED TO INTERLOCK WITH A ZERO GRAVITY SURFACE. PHOTOGRAPH PROVIDED BY THE LANGLEY RESEARCH CENTER.



B — A SAMPLE SPHERE OF AN INTERLOCKING STRUCTURE INTERLOCKING WITH A ZERO GRAVITY SURFACE.

FIGURE E—26. ZERO GRAVITY SURFACE

3.7 ZERO GRAVITY SURFACE AND INTERLOCKING STRUCTURE (CONTINUED)

called the interlocking structure which locks and unlocks upon application of small forces. The primary surface is constructed by attaching small spheres by means of elastic pins. Similar spheres or other shaped bodies are attached to the secondary surface and located at intervals equal to or greater than twice the spacing of the primary surface. The spacing is dependent on the size of the spheres used and the magnitude of the forces desired. The force desired is also controlled by the stiffness of the elastic pins and their length, as well as the shape, size and number of the spheres (or other shaped elements) attached to the secondary surface.

Primary Surface:	
Sphere diameter	0.125 in. (0.32 cm)
Distance between pins	0.15 in. (0.40 cm)
Secondary Surface Pin	
Sphere diameter	0.125 in. (0.32 cm)

The zero gravity surface and interlocking structure can be applied on any two objects that are to be attached to one another. The primary surface can be used as a floor in a space vehicle and the secondary surface placed on the bottom of the astronaut's boot. A primary surface can be placed on a plate near a worksite and the secondary surface can be attached to hand tools (Ref. Figure E-26).

Advantages and Disadvantages

The zero gravity surface and the interlocking structure can be constructed of non-magnetic and non-outgassing materials and can be universally applied to any desirable area of either the interior or exterior of the spacecraft. It can be easily cleaned or sterilized and can be rigidly constructed to withstand loads of earth gravity conditions. The construction is lightweight and has no moving parts.

4.0 SPECIAL RESTRAINT DEVICES

4.1 KUPU LATCH

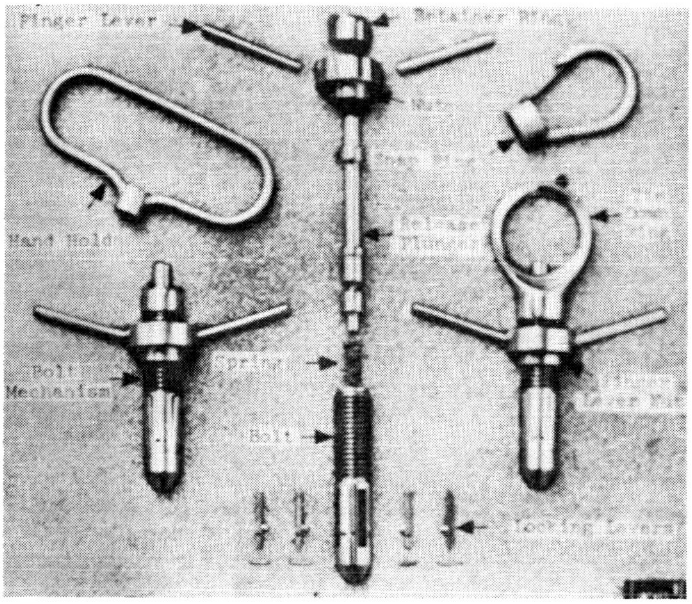
Description

The KUPU latch was designed to provide a quick connect and disconnect attachment point for restraint devices and tethers or to serve as a quickly emplaced fastener for in-space assembly. The latch, shown in Figure E-27, is inserted into a hole just slightly larger than the diameter of the bolt mechanism. Once the latch has been inserted past the locking levers, the levers spring outward and prevent extraction of the latch. The finger lever nut can be rotated into position by a gloved astronaut so that the latch is secured. The latch can now serve as an attachment point for a snap ring, a tie down ring, or a handhold attachment. When the latch is to be removed, the finger lever nut is loosened. When the release plunger is pressed, the locking levers retract within the bolt and the bolt can be removed from the hole. The retainer ring is permanently emplaced by the manufacturer thus preventing the nut and bolt from ever disengaging.

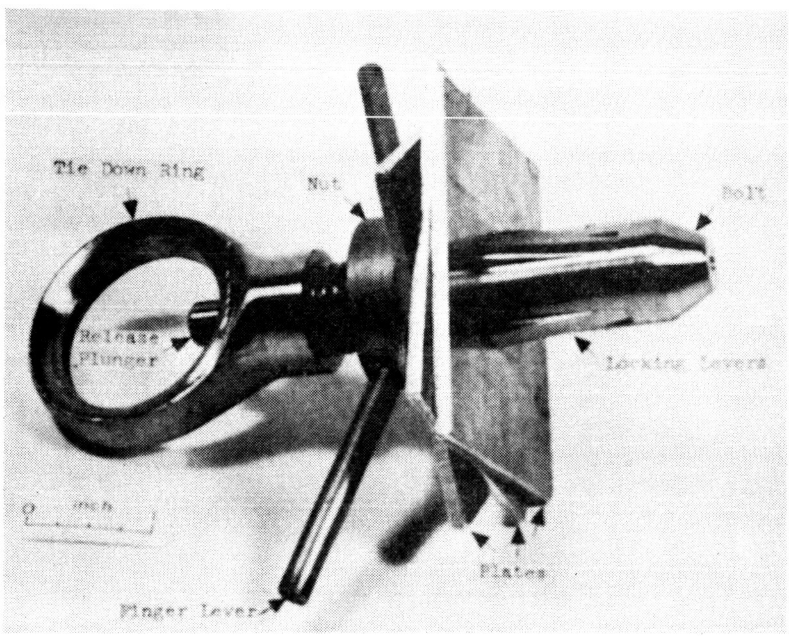
Performance

Two (2) KUPU latches of different sizes have been fabricated, the larger was able to withstand a tensile force of over 600 lbs.

4.1 KUPU Latch - Continued



A. KUPU LATCH



B. KUPU LATCH JOINING THREE PLATES

FIGURE E-27. KUPU LATCH

4.1 KUPU LATCH (CONTINUED)

Advantages and Disadvantages

The KUPU latch permits one man, space assembly and tie-down. It is designed to reduce the number of loose parts to a minimum. The nut and bolt form a single unit and are not separated in use. The usual difficulty of mating a nut and bolt assembly is eliminated and thus one-handed emplacement and removal is possible. The latch does not require the use of any hand tools but does require the presence of a pre-cut hole.

4.2 EXTENDABLE BOOM

Description

The extendable, shown in Figure E-28, boom is basically a box that contains a roll of sheet metal that is pretensioned so that it will curl up into a tube with the aid of the guiding cone as it is pulled off the feed roller. The boom is extended by pulling out the sheet metal strip and is retracted by pushing it back into a roll in the same manner as a steel tape measure. When the boom is extended, one end of the boom can be attached to a space vehicle and the housing on the other end can be used for working platform.

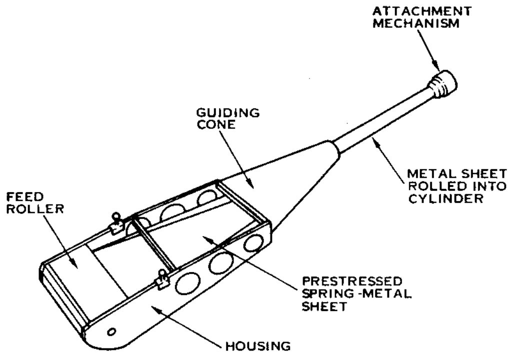


FIGURE E—28. EXTENDABLE BOOM

Advantages and Disadvantages

Unavailable.

4.3 RESTRAINT BUTTONS AND APPLICATOR

Description

The restraint buttons and applicator system was designed to emplace adhesive buttons on space vehicles for providing attachment points for tethers. This system, shown in Figure E-29, is an integral part of the Martin space tool kit and was used to restrain the kit and stabilize the working astronaut. Each of its seven parts has its own pocket in the tool kit case and functions as follows:

(1) The restraint buttons are aluminum disks with swivel eyelets for attaching a tether. A wire grid of No. 32 copper wire is embedded in a thin layer of FM-98 epoxy film on the face of each disk. An electric current through this grid heats the epoxy to a bonding temperature.

(2) The screwdriver ratchet handle, generally used as a handle for screwdriver bits, serves as a handle for the applicator.

(3) The button holder unit that holds the restraint button also provides an electrical contact for the restraint button. The unit contains a thermocouple that extends through a hole in the restraint button and measures the bonding temperature.

(4) The application control unit holds an indicator that signals when a bonding temperature of 450°F (504°K) is reached. The thermocouple circuits and a pressure probe allows a controlled impulse to seat the bottom as the epoxy softens.

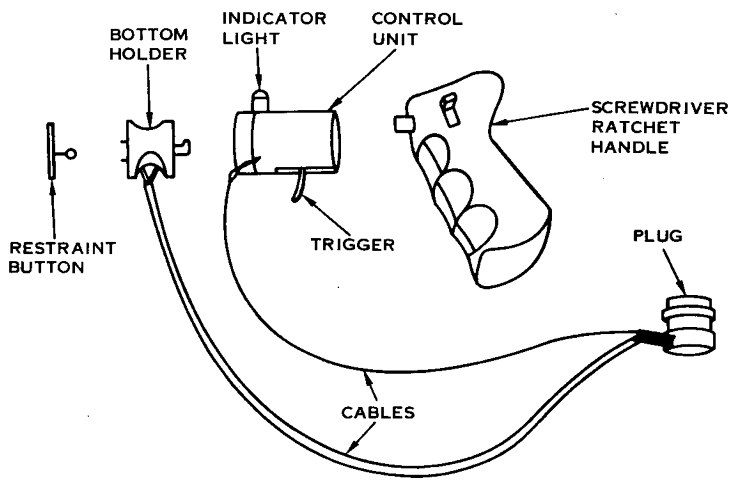
(5) An electric plug fits into an electric socket in the tool kit case and draws power from a battery in the center of the case through the electronics package.

(6) The electronics package contains the monitoring circuits for the applicator and is permanently located in the tool kit case near the battery.

(7) Two (2) cables carry current to and from the various parts of the system.

4.3 RESTRAINT BUTTONS AND APPLICATOR (CONTINUED)

Application of the system requires the operator to remove a restraint button and assemble the various parts of the applicator from the case. Next, the operator presses a restraint button against the adherend and actuates the power switch until the signal light indicates a bonding temperature. Some slack in the cable between the control unit and the holder unit allows the units to separate and the operator to drift away in reaction to the force applied to the button to prevent pulling on the button before a good bond is formed.



RESTRAINT BUTTONS AND APPLICATOR

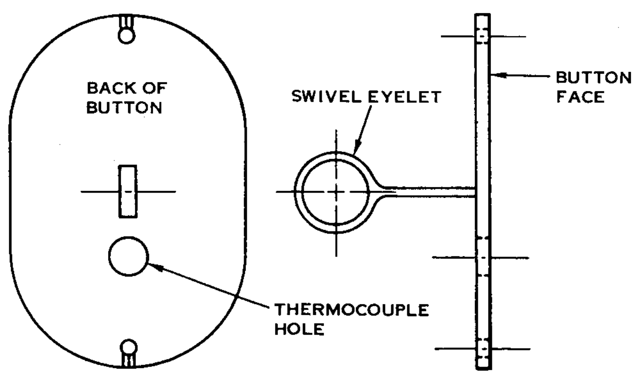


FIGURE E–29. RESTRAINT BUTTONS

4.3 RESTRAINT BUTTONS AND APPLICATOR (CONTINUED)

	Length	Width	Height	Weight
Screwdriver Handle	7.0 in. (18 cm)	3.0 in. (7.6 cm)	8.0 in. (20 cm)	0.75 lb (0.34 kg)
Control and Holder Units Coupled	3.7 in. (9.4 cm)	1.3 in. (3.3 cm)	2.8 in. (7.1 cm)	0.75 lb (0.34 kg)
Cables	3 ft. (0.92 m)			

Restraint Button

Diameter	1.13 in. (2.87 cm)
Height (with eyelet)	0.5 in. (1.27 cm)
Thickness	0.03 in. (0.08 cm)
Weight	0.063 lb (0.028 kg)
Power Requirement	8-10 A, 10-12 V
Material	Aluminum

Performance

Laboratory tests have shown that the buttons will withstand loads greater than 50 pounds when a bonding temperature of 450°F (504K) was reached. Eleven to 90 seconds were required to reach the bonding temperature in tests using various thicknesses of aluminum sheet varying from 0.016 in. to 0.100 in. and various initial temperatures from -160°F (166°K) to 70°F (294°K).

Advantages and Disadvantages

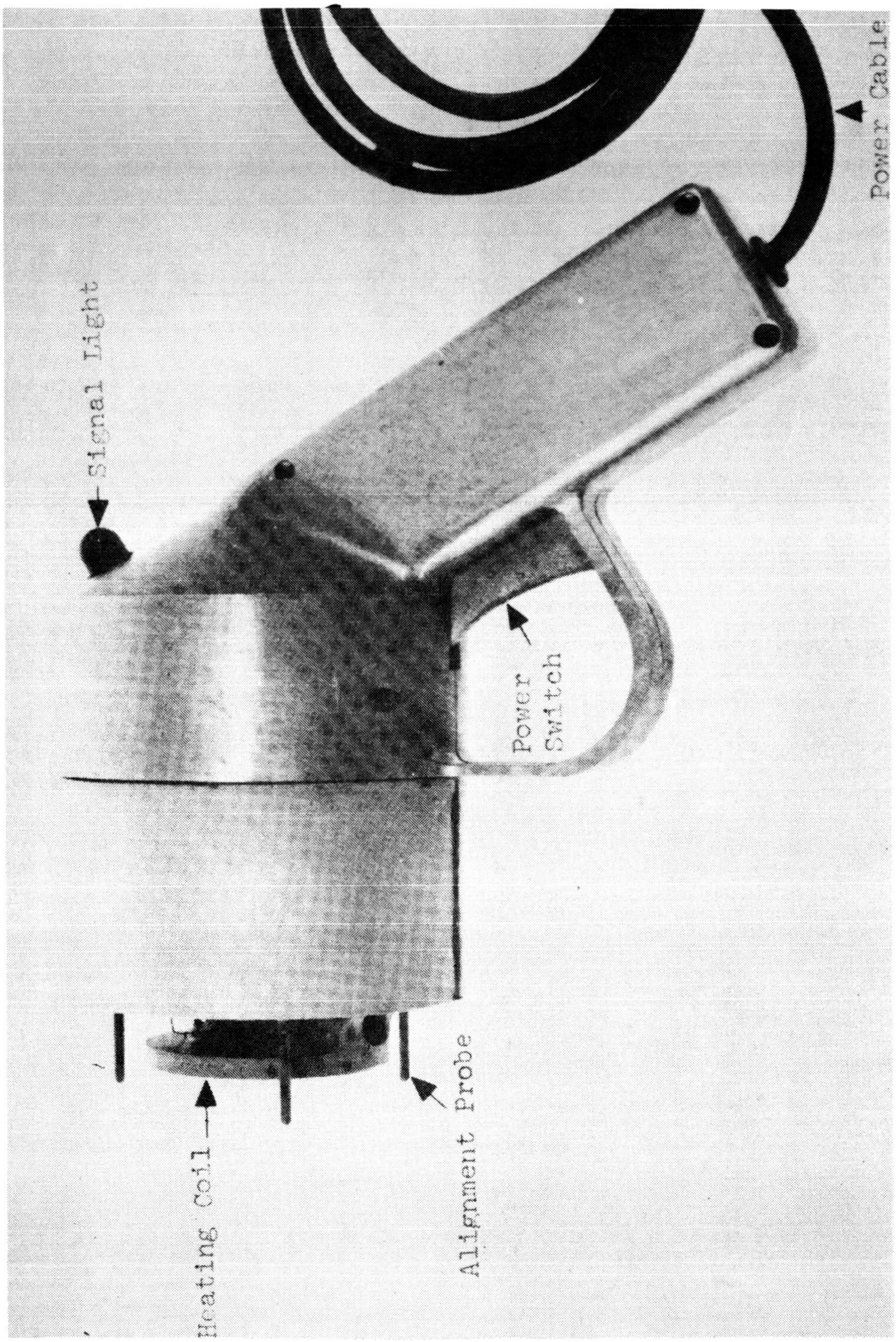
A suited operator is likely to have difficulty assembling the various parts. The long cables are likely to interfere with the operator.

4.4 STUD BONDING TOOL

Description

The stud bonding tool, shown in Figure E-30, was developed to bond a stud and swivel assembly using a thermoplastic adhesive to either metal or plastic, internal or external to the vehicle, and in atmosphere or vacuum.

4.4 Stud Bonding Tool - Continued



4.4 Stud Bonding - Continued

The studs and swivel assembly, bonded in place, provide an attachment point with quick disconnect capability. The swivel can also be removed to mount equipment directly on the stud.

Total Weight	2.5 lb (1.14 kg)
Power Requirements	28 V, 1 kW

The stud bonding tool is designed to be hand held and to use an external, direct current power supply. A heating element heats the stud, which is retained in the tool by means of the swivel, to as much as 707°F (648°K) in 30 seconds. When the right temperature is reached, an adjustable sensing unit signals that the stud is sufficiently heated. The temperature is maintained until the stud is released for application. However, the stud cannot be released until an integral alignment system has assured that the stud will be applied perpendicular to the surface to be bonded. When released, a spring snaps the swivel guided stud against the adherend, where, a thermoplastic adhesive forms a bond, providing a load point capable of holding 500 pounds perpendicular to the bond line at room temperature.

APPENDIX F

TRANSLATION DEVICES

1.0 MANUAL TRANSLATION

Results from both the Gemini and Apollo programs have indicated that manual translation techniques are effective for astronaut maneuvering around spacecraft surfaces. Concepts studied in the manual locomotion category are presented in Table F-1.

CONCEPT	REFERENCE PARAGRAPH
HANDHOLDS	1.1
HANDRAILS	1.2
ASTROGRID SHOES	1.3
MAGNETIC SHOES	1.4
VELCRO SHOES	1.5
SOARING	1.6

TABLE F-1. MANUAL TRANSLATION CONCEPTS

1.1 Handholds

Handholds have been qualified on both the Apollo and Gemini programs and have been shown to offer an excellent hand-over-hand translation capability as shown in Figure F-1. They can either protrude or be recessed from the surface depending on the application or vehicle interfaces.

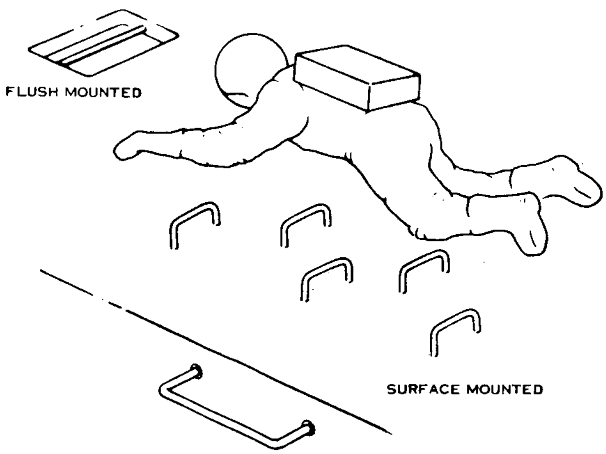


FIGURE F-1. HANDHOLDS

For mobility, the recessed type have an advantage in that they do not present "elbow knockers". For restraint, the protruding type would probably afford a better purchase.

1.1 Handholds (Continued)

Handholds can also be portable or permanent, again, depending on application and vehicle interface requirements. Portable handholds can incorporate mechanical means or velcro patches for adhesion to the surface. Mechanical devices such as pip-pins afford a more positive connection as Gemini experience indicates velcro holding forces were not sufficient to accommodate controlled maneuvering or control of body attitude. Portable devices offer an advantage over permanent installations in that they do not cause potential aerodynamic and heating problems. They also avoid "cluttering up" the vehicle surface with permanent protrusions. Inherently, however, portable devices have a disadvantage in that they must be carried by the astronaut over the course of his translation. Vehicle interfaces are the predominant factor in the selection between portable or permanent handholds. Frequently traveled routes would probably be most amenable to permanent type devices whereas seldom used paths do not merit the permanent protrusion problem. Table F-2 presents a summary of the advantages and disadvantages associated with handholds and handrails.

ADVANTAGES	DISADVANTAGES
REQUIRES NO ELECTRICAL POWER	REQUIRES USE OF ONE OR BOTH HANDS
LIGHT WEIGHT	DIFFICULT TO MANAGE LARGE PACKAGES
SIMPLE	STRUCTURAL INTERFACE WITH VEHICLE - SHOULD BE INCORPORATED IN VEHICLE DESIGN LIMITED TO LIMITED TO VEHICLE SURFACE TRANSLATION
FLIGHT QUALIFIED	EXCESSIVE USE IS TEDIOUS ON HANDS AND WRISTS
DURABLE	NEED VEHICLE STRUCTURAL SUPPORT
RELIABLE	
READY MADE TETHER ATTACH POINTS	
MAINTENANCE FREE	
APPLICABLE AT ALL LEVELS OF GRAVITY	
POSITIVE CONTROL	

TABLE F-2. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF HANDHOLDS

Design - Design requirements for handholds are described in Section 10.0 (Restraints).

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1.2 Handrails

Handrails, shown in Figure F-2, are similar in design to handholds except they are continuous over the translation path rather than the discrete interval spacing of handholds.

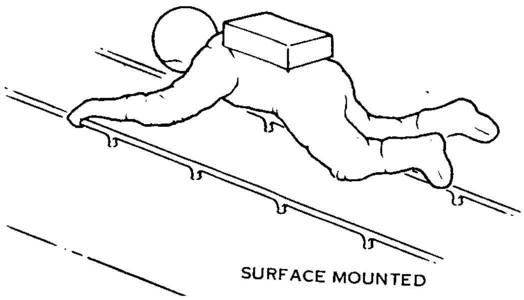

FIGURE F—2. HANDRAILS

Selection of protruding or recessed handrails is dependent on application and vehicle interface constraints. Handrails can be either single or dual parallel rails (16 to 24" apart) with the two rails providing more stability at the expense of increased weight for the second rail. The most common translation position is one in which the elbows and knees are slightly bent and the torso is nearly parallel to the surface.

The relative advantage of handrails over handholds is their continuity permitting an infinite number of hand locations during translation to achieve optimum stability. A weight penalty over that required for handholds must be paid for this advantage.

1.2 Handrails (Continued)

The advantages/disadvantages of handrails as an overall translation are presented in Table F-3.

ADVANTAGES	DISADVANTAGES
REQUIRES NO ELECTRICAL POWER	REQUIRES USE OF ONE OR BOTH HANDS
LIGHT WEIGHT	DIFFICULT TO MANAGE LARGE PACKAGES
SIMPLE	STRUCTURAL INTERFACE WITH VEHICLE - SHOULD BE INCORPORATED IN VEHICLE DESIGN LIMITED TO LIMITED TO VEHICLE SURFACE TRANSLATION
FLIGHT QUALIFIED	EXCESSIVE USE IS TEDIOUS ON HANDS AND WRISTS
DURABLE	NEED VEHICLE STRUCTURAL SUPPORT
RELIABLE	
READY MADE TETHER ATTACH POINTS	
MAINTENANCE FREE	
APPLICABLE AT ALL LEVELS OF GRAVITY	
POSITIVE CONTROL	

TABLE F-3. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF HANDRAILS

The design requirements for handrails have previously been presented in Section 10.0 (Restraints).

Bungee cords stretched taut along the spacecraft surface as well as a cargo net stretched over the surface could also be considered in the handrail category. The translation instability from these non-rigid devices, however, makes them unattractive as astronaut maneuvering aids.

1.3 Astrogrid Shoe

This translation aid, shown in Figure F-3, consists of a floor grid surface of triangular holes in a hexagonal array into which shoes with interfacing, positive triangular shapes or cams are inserted.

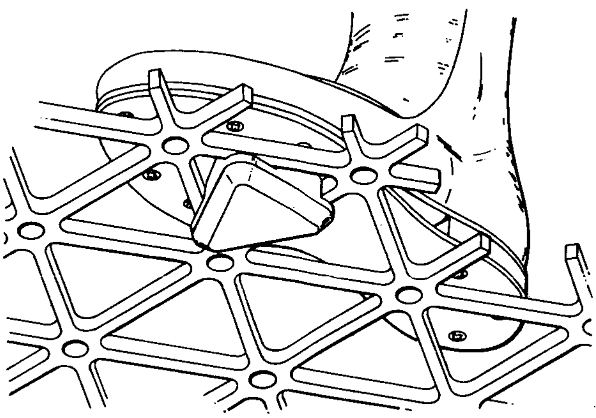

FIGURE F—3. ASTROGRID SHOES

By twisting the shoe a given amount, it becomes securely fastened to the grating. Testing in zero gravity has indicated that walking devices such as this are more difficult to use than hand-over-hand translation techniques. This fact coupled with the vehicle interface and weight penalty required to provide the secondary grating surface makes this approach unacceptable for Shuttle EVA application.

1.3 Astrogrid Shoe (Continued)

Advantages and disadvantages associated with this concept are listed in Table F-4.

ADVANTAGES	DISADVANTAGES
FREES BOTH HANDS	DIFFICULT/UNNATURAL TO USE
POSITIVE RESTRAINT	SLOW TRANSLATION
	VEHICLE PENALTIES (WEIGHT AND SURFACE DESIGN)
	REQUIRES SPECIAL SHOES

TABLE F-4. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF ASTROGRID SHOES

1.4 Magnetic "Shuffler" Shoe

This concept, shown in Figure F-4, uses a shuffling technique for translating (sliding one foot forward on a low coefficient of friction surface, maintaining constant contact with the floor).

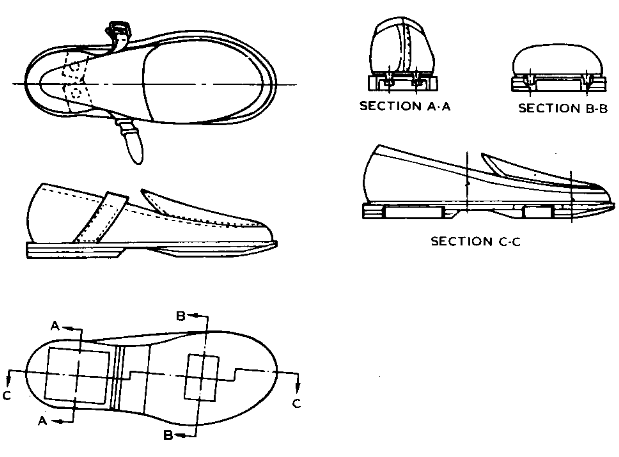

FIGURE F-4. MAGNETIC 'SHUFFLER' SHOES

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1.4 Magnetic "Shuffler" Shoe (Continued)

It requires the high weight penalty of an iron surface over which to translate, and testing indicates the "shuffing" method is quite unnatural and requires significant attention. These facts make it impractical as a translation aid. Table F-5 lists overall advantages and disadvantages associated with this concept.

ADVANTAGES	DISADVANTAGES
NO ELECTRICAL POWER REQUIRED	SOFT IRON FLOOR IS AN INTEGRAL PART OF RESTRAINT SYSTEM - PRESENTS EXCESSIVE WEIGHT PENALTY FOR OTHER THAN LIMITED APPLICATION
FOOTWEAR CAN BE WORN IN ARTIFICIAL GRAVITY ENVIRONMENT AND SERVES AS PRIMARY FOOTGEAR	INCORPORATION REQUIRES SHIELDING OF INSTRUMENTATION AND DISPLAYS
	REQUIRES INDIVIDUAL ISSUE TO EACH CREWMAN

TABLE F—5. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF MAGNETIC 'SHUFFLER' SHOES

1.5 Velcro Shoes

Shoes with velcro patches on the soles and mating velcro on the translation surface is another walking type locomotion aid. Past experience with velcro on the Gemini program indicates that a velcro bond is not sufficient to accommodate controlled maneuvering or control of body attitude. This deficiency, combined with zero gravity test results concerning the difficulty in using walking devices as opposed to hand-over-hand translations, makes velcro shoes unacceptable for translation on Shuttle EVA's.

1.5 Velcro Shoes (Continued)

Overall advantages and disadvantages are listed in Table F-6.

ADVANTAGES	DISADVANTAGES
LEAVES HANDS FREE FOR OTHER TASKS	INSTABILITY PROBLEMS
NO ELECTRICAL POWER	INSUFFICIENT BOND
	VEHICLE INTERFACE REQUIRES VELCRO LINED SURFACES

TABLE F–6. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF VELCRO SHOES

1.6 Soaring

Soaring presents a short distance translation technique consisting of pushing off a surface, floating to the ultimate destination, and cushioning the impact on arrival with hands or feet, thus arresting all motions tending to cause rebound, tumble or overshoot. There are two (2) major soaring categories: free soaring where no noticeable effect from a tether is involved and aided soaring where the tether can be used to apply impulse or torque to the astronaut.

Push-off velocities of 12 ft/sec are possible, but velocities of 4 ft/sec and lower are recommended to achieve adequate thrust alignment to minimize tumbling. Direction of initial take-off cannot reasonably be expected to be less than 10° of the desired direction. In general, control of body position prior to impact is a significant problem with this approach and limits its use to cases where it is not possible to provide handholds or handrails and where direct docking or mechanically assisted locomotion is not available. Therefore, this technique was not considered as a primary mode of translation for Shuttle EVA, but should not be eliminated since local personnel rescue and limited unscheduled operational problems (such as failure to hard dock) may require soaring short distances.

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1.6 Soaring (Continued)

Advantages and disadvantages are listed in Table F-7.

ADVANTAGES	DISADVANTAGES
NO VEHICLE INTERFACE	DIFFICULT TO CONTROL BODY POSITION PRIOR TO IMPACT
HANDS FREE MANEUVERING	SHORT DISTANCE APPLICABILITY
NO HANDWARE REQUIRED	REQUIRES MORE ZERO "G" TESTING
MAINTENANCE FREE	POSSIBILITY OF COLLISIONS OR EQUIPMENT DAMAGE
NO ELECTRICAL POWER	DIFFICULT TO ACHIEVE ACCURATE DIRECTION

TABLE F-7. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF SOARING

1.7 Summary Evaluation

Based on the preceding presentation of various manual translation devices, the astrogrid shoes, the magnetic "shuffler" shoes and the velcro shoes were found unacceptable for Shuttle EVA usage. This finding stems primarily from the fact that zero gravity tests have indicated a difficulty in using walking devices as opposed to hand-over-hand translations. Thus only handholds, handrails and soaring remain as manual translation candidates. Both handholds and handrails have similar advantages and disadvantages as well as applicability, and are the selected manual translation technique. Soaring, although not selected as a primary translation mode, is not eliminated since rescue operations may require soaring short distances.

2.0 SELF-POWERED TRANSLATION

Self-powered maneuvering devices offer an extensive translation range that is not limited to the vehicle surface such as is the case for manual techniques. Their applicability lies mainly in maneuvers away from the vehicle and to vehicle surface areas where it is impractical to locate manual devices due either to the length of travel or limited translation occurrences along a path.

Table F-8 presents basic powered maneuvering devices that have been investigated for the Shuttle EVA missions.

CONCEPT	REFERENCE PARAGRAPH
HAND-HELD (HHMU)	2.1
BACK MOUNTED	2.2
PLATFORM	2.3

TABLE F—8. MANEUVERING DEVICE CONCEPTS

2.1 Hand-Held Maneuvering Unit (HHMU)

The Hand-Held Maneuvering Unit, shown in Figure F-5, consists of one (1) tractor and two (2) pusher jets that are hand-aimed in the direction of required translation -- pusher jets for forward motion, tractor jets for stopping.

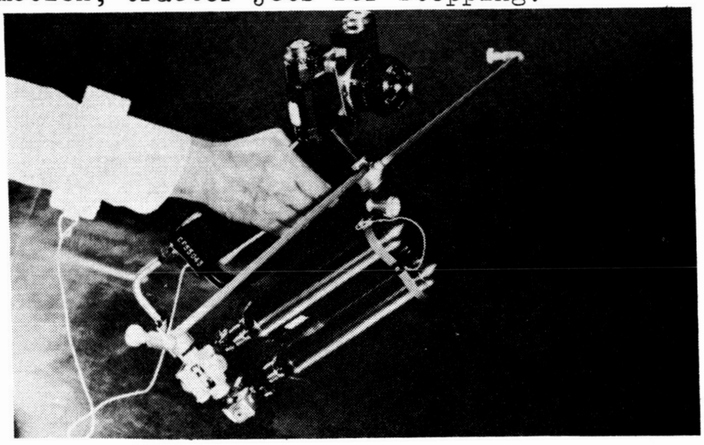

FIGURE F—5. GEMINI IV HAND HELD MANEUVERING UNIT

2.1 Hand-Held Maneuvering Unit (HHMU) (Continued)

Rotations are accomplished by offsetting the thrust vector from the desired axis of rotation. The HHMU was initially utilized during the Gemini program in the general vicinity of the spacecraft.

Equipment problems caused the experience to be brief and assessment of its performance capabilities was inconclusive.

The HHMU's are operated by squeezing a trigger mechanism to operate a throttle valve and provide gas flow to either the tractor or pusher thrusters. The thrust level is normally proportional to trigger displacement. The characteristics of the HHMU's designed for the Gemini program are shown in Table F-9.

GEMINI HAND HELD MANEUVERING UNIT CHARACTERISTICS	GEMINI IV	GEMINI VIII	GEMINI X
HHMU WEIGHT (LBS)	7.5	3*	3*
WEIGHT OF PROPELLANT (LBS)	.7	18	10.75
PROPELLANT (GAS)	OXYGEN	FREON-14	NITROGEN
THRUST, TRACTOR OR PUSHER (LBS)	0 TO 2	0 TO 2	0 TO 2
SPECIFIC IMPULSE CALCULATED (SEC)	59	33.4	63
TOTAL IMPULSE (LB-SECS)	40	600*	677*
TOTAL AVAILABLE VELOCITY INCREMENT (FT/SEC)	6	54	84
TRIGGER PRELOAD (LBS)	15	15	5
TRIGGER FORCE AT MAXIMUM THRUST (LBS) . .	20	20	8
STORAGE TANK PRESSURE (PSIA).	4000	5000	5000
REGULATED PRESSURE (PSIA)	120	110+15	125+5
NOZZLE AREA RATIO	50:1	51:1	51:1

*THE NITROGEN PROPELLANT TANK WAS MOUNTED IN THE ADAPTER SECTION. THE WEIGHT STATED IS FOR THE HHMU ONLY AND DOES NOT INCLUDE THE WEIGHT OF THE UMBILICAL, PROPELLANT TANK AND PROPELLANT.

TABLE F—9. GEMINI HAND HELD MANEUVERING UNIT CHARACTERISTICS

A hydrazine HHMU was developed by Rocket Research which provided over six (6) times the total velocity increment available from the Gemini IV unit. This was achieved primarily as the result of utilizing the higher specific impulse and higher density of this liquid monopropellant fuel. The propellant used was a hydrazine - water mix (51% NeH_4, 49% H_2O). Thermal considerations required the addition of the water to preclude excessive temperatures during operation.

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2.1 Hand-Held Maneuvering Unit (HHMU) (Continued)

A HHMU, shown in Figure F-6, is currently undergoing test as part of the Skylab M-509 Experiment.

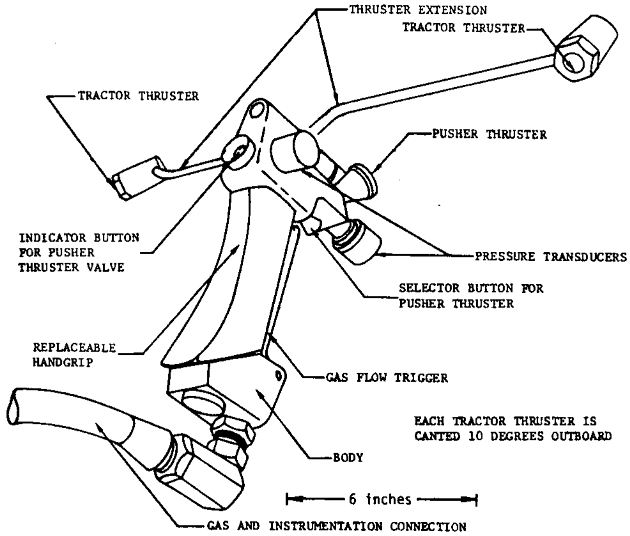


FIGURE F-6. SKYLAB HAND HELD MANEUVERING UNIT

Characteristics of this unit are contained in Table F-10.

SKYLAB HAND HELD MANEUVERING UNIT CHARACTERISTICS	
WEIGHT OF PROPELLANT (LBS)	11.2/TANK
HHMU WEIGHT (LBS)	3.0
PROPELLANT (GAS)	NITROGEN
THRUST, TRACTOR OR PUSHER (LBS)	0 TO 3.00±0.25
SPECIFIC IMPULSE CALCULATED (SEC)	58±2
TOTAL IMPULSE (LB-SEC)	600/TANK
TOTAL AVAILABLE VELOCITY INCREMENT (FT/SEC)	53
TRIGGER PRELOAD (LBS)	-
TRIGGER FORCE AT MAXIMUM THRUST (LBS)	-
STORAGE TANK PRESSURE (PSIA)	3000
REGULATED PRESSURE (PSIA)	145±10
NOZZLE AREA REATION (DESIGNED FOR 5 PSIA ENVIRONMENT, TRACTOR/PUSHER)	2.75/3.02

TABLE F-10. SKYLAB HAND HELD MANEUVERING UNIT CHARACTETISTICS

2.1 Hand-Held Maneuvering Unit (HHMU) (Continued)

Although flight testing results of the Gemini HHMU's were somewhat inconclusive, ground based simulation testing indicated that confused tumbling motions might occur due to inertia coupling effects resulting from excessive rotational velocities. Results to date of the M-509 ground testing simulation on the HHMU indicate that stability and control problems still exist with this concept. These problems stem primarily from the fact that the forces from the jets are not always through the center of gravity of the astronaut, and thus unwanted rotations, pitches and yaws are experienced. The astronaut has to continually fire the thrusters to maintain a stable desired maneuver. Such actions result in a considerable expenditure of fuel and astronaut energy. A summary of advantages and disadvantages associated with the HHMU is contained in Table F-11.

ADVANTAGES	DISADVANTAGES
SIMPLE, CHEAP, LIGHT	TIES UP ONE HAND
DONNING IS EASY	DIFFICULT TO MAINTAIN STABILITY
COLLAPSES FOR MINIMAL STORAGE VOLUME	DIRECTIONAL CONTROL IS DIFFICULT

TABLE F-11. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF HAND HELD MANEUVERING UNIT

2.2 Back-Mounted Powered Translation

2.2.1 General

A back-mounted propulsion device is the recommended approach for self-powered astronaut translation for Shuttle EVA operations. This conclusion is based on both task requirements and the basic performance capability of such a powered device.

2.2.1 General (Continued)

The most recent experience with a back-mounted propulsion system has been on testing of the Skylab Experiment M-509 Automatically Stabilized Maneuvering Unit (ASMU) and on the Skylab Experiment T-020 Foot Controlled Maneuvering Unit (FCMU). These experiments are part of an overall program to develop a capability to support and enhance future manned spaceflight missions with an astronaut maneuvering base. The purpose of the experiment is to obtain engineering and technological data in flight on both selected maneuvering techniques and man performance capability for specific maneuvering tasks.

Past experience with the Astronaut Maneuvering Unit (AMU) from the Gemini program as well as the Integrated Maneuvering Life Support System (IMLSS) and the Astronaut Maneuvering Unit Brassboard (AMUB) were utilized in the design of these Skylab experiments.

Preliminary test results on the Skylab program have yielded significant confidence concerning the Astronaut's ability to translate effectively with a back-mount propulsion unit even without any automatic stabilization provisions. Possibly only a single mode gyro control will be required for emergency conditions causing loss of control.

2.2.2 Shuttle Back-Mounted Self-Powered Maneuvering Unit

This section presents a preliminary sizing of back-mounted self-powered maneuvering unit for the Space Shuttle.

2.2.2.1 System Requirements and Constraints

Utilizing a typical Shuttle EVA mission as defined in Appendix A, along with the NASA recommended acceleration of 0.3 ft/sec^2 and a mass of 400#, it was determined that approximately 400 lb-seconds total impulse is required to achieve this mission. Adding on a margin of safety to correct for maneuvering errors and providing for a growth potential, a total impulse range of 500 to 5000 lb-seconds was studied.

2.2.2.1 System Requirements and Constraints (Continued)

For the purpose of this trade-off, the following mass was considered:

175 lb_m	Astronaut
75 lb_m	PLSS/ELSS
45 lb_m	Load
40 lb_m	Maneuvering System
65 lb_m	Suit
400 lb_m	Total Mass

For a translation acceleration of 0.3 ft/sec^2, a 4 lb_f thrust is required in each direction.

2.2.2.2 Thruster Location

Figure F-7 defines yaw, pitch and roll as well as translation directions as they are utilized in this study.

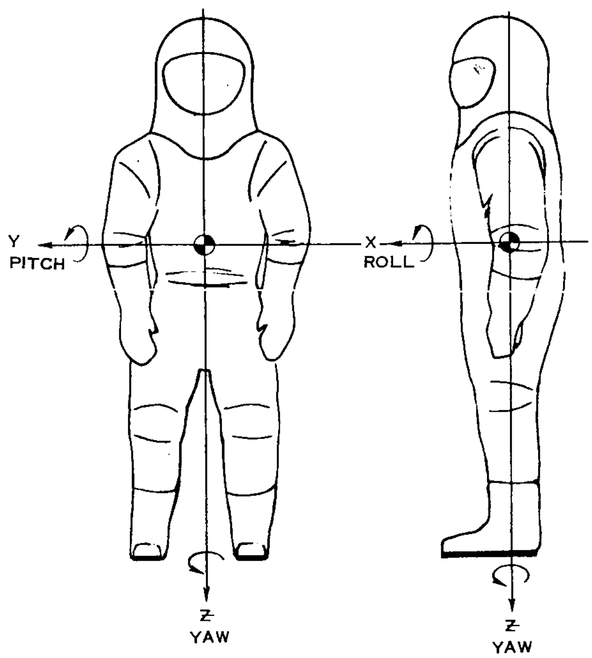


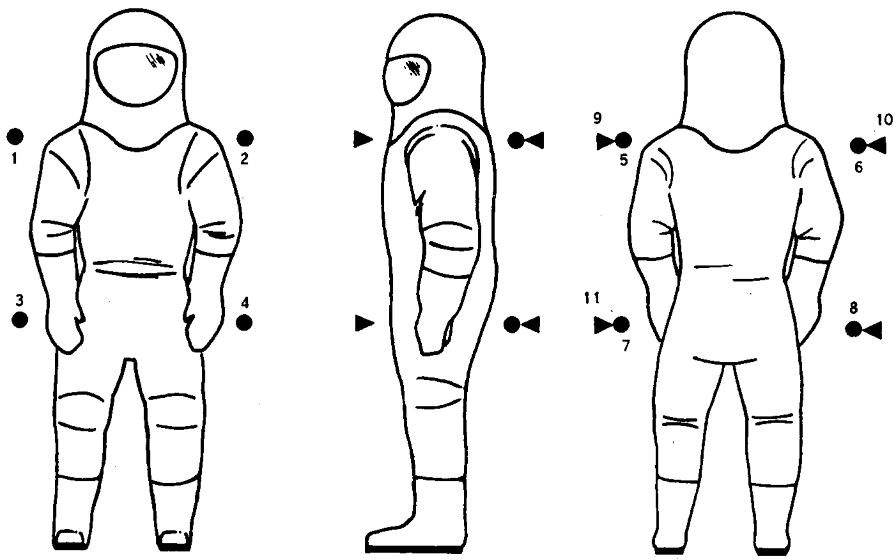
FIGURE F–7. ATTITUDE AND TRANSLATION AXES

For the purpose of this analysis, a twelve thruster (2 lb_f each) arrangement as shown in Figure F-8 was selected. This system provides for 4 degrees of freedom (DOF) - 1 translation and 3 attitude. Translation along the X axis is through the center of gravity (CG) to preclude inducing any unwanted attitude changes. Attitude maneuvers are achieved by couples through the CG to eliminate any cross-coupling effects.

2.2.2.2 Thrust Location Unit - Continued

Redundancy is provided in all 4 DOF's, however, roll redundancy cannot be provided by couples and thus some cross-coupling can occur in this back-up mode. A 5th DOF, translation along the Y axis, is possible but is not through the CG and thus introduces some yaw.

More thrusters could be added to provide a full 6 DOF system if such a capability is required. Provisions for translation along the Z axis, however, could result in some plume impingement effects upon the suit. The system chosen, although only 4 DOF, is an adequate baseline for analytical purposes as it is the minimum acceptable design and only the addition of thrusters is required to increase it to a 6 DOF system if required.



THRUSTER LOGIC

	PRIMARY +	PRIMARY −	BACK-UP +	BACK-UP −
PITCH	(1, 8)	(3, 6)	(2, 7)	(4, 5)
YAW	(1, 5)	(2, 6)	(3, 7)	(4, 8)
ROLL	(9, 12)	(10, 11)	(9 OR 12)	(10, OR 11)
X TRANS	(5, 8)	(2, 3)	(6, 7)	(1, 4)

FIGURE F-8. THRUSTER ARRANGEMENT

2.2.2.3 System Comparison

Five propulsion systems (hydrazine, hydrazine and water, freon boil-off, oxygen and nitrogen) were analyzed for potential use in a back-mounted astronaut maneuvering unit. The basic schematics for each of these systems are presented in Figures F-9, F-10 and F-11. The thruster configuration is the same for each system and is described above.

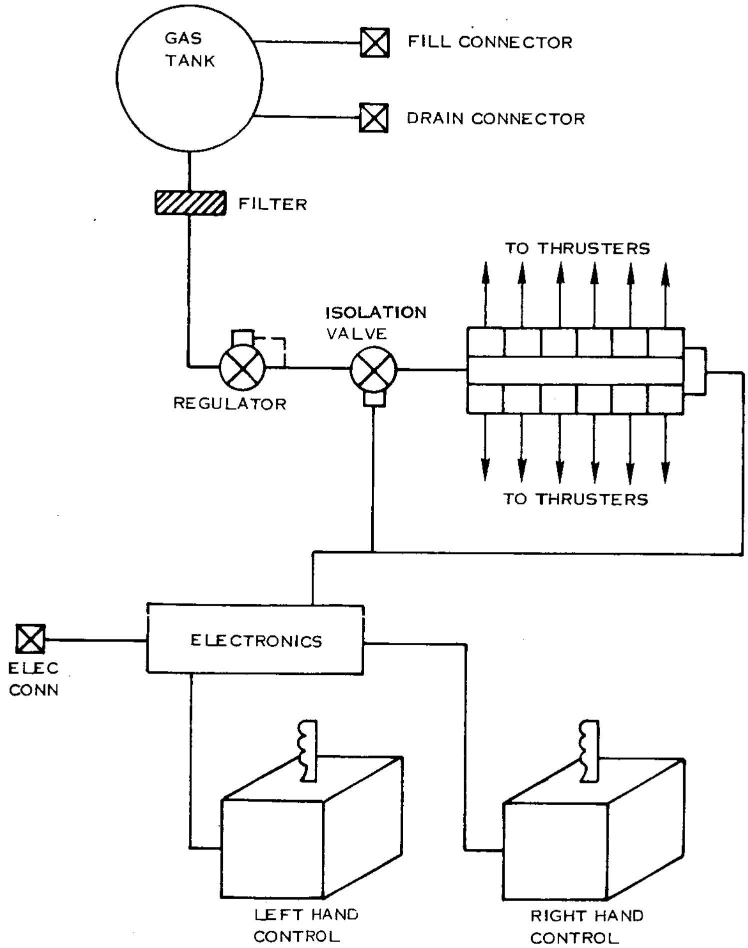


FIGURE F—9. COLD GAS SYSTEM SCHEMATIC

2.2.2.3 System Comparison (Continued)

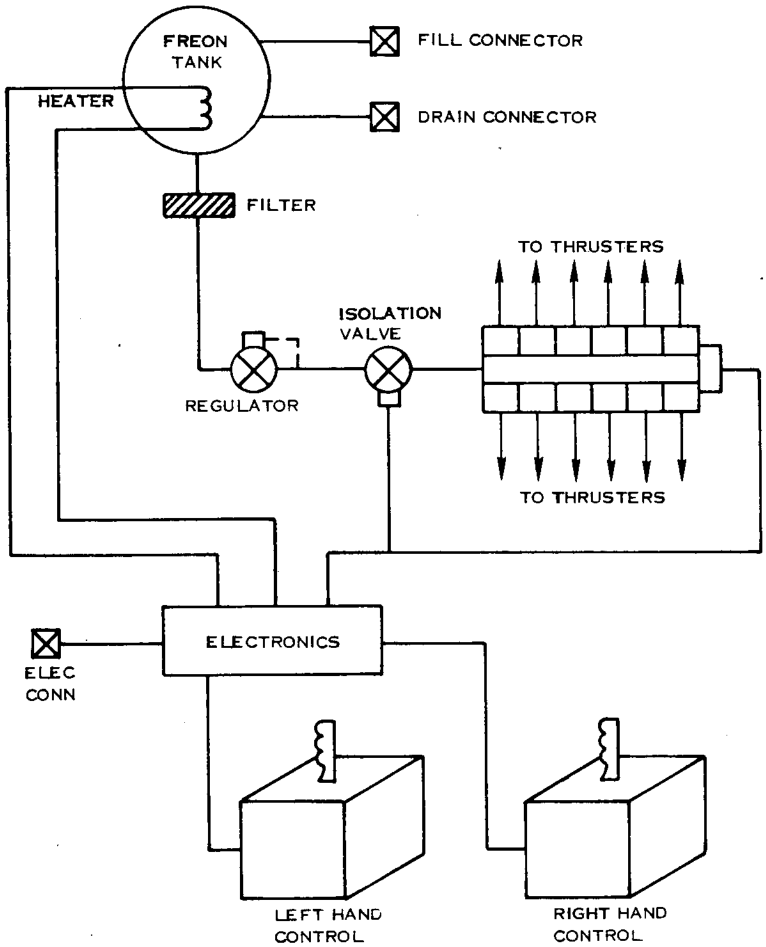


FIGURE F-10. FREON BOIL-OFF SYSTEM SCHEMATIC

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2.2.2.3 System Comparison (Continued)

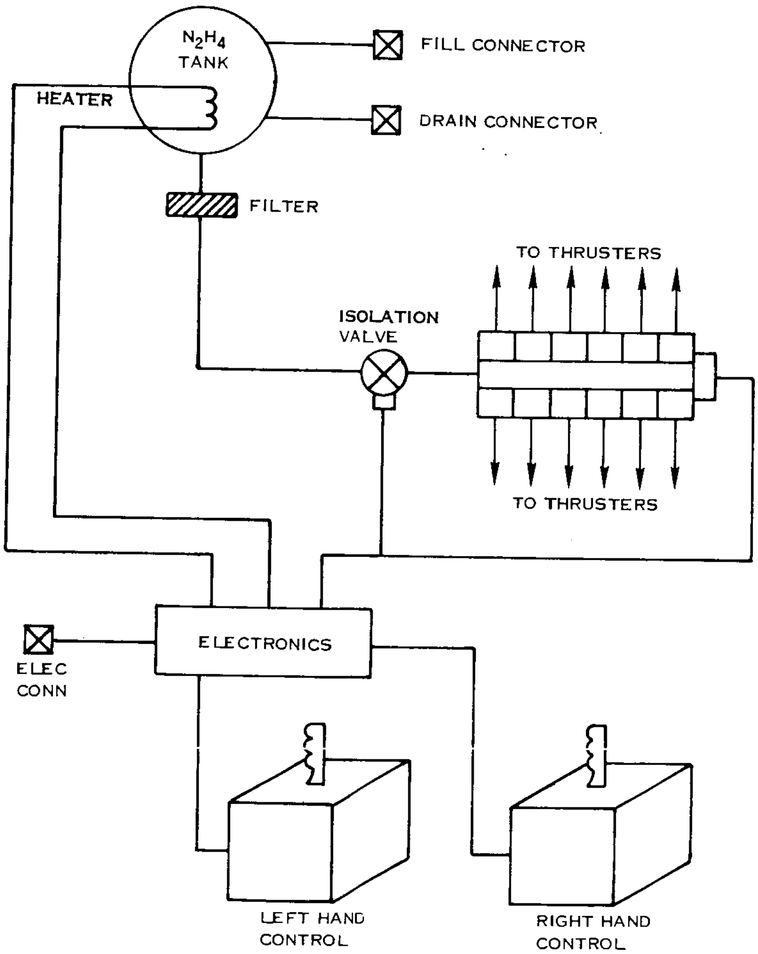

FIGURE F–11. HYDRAZINE SYSTEM SCHEMATIC

2.2.2.3 System Comparison (Continued)

The results of the system weight and tank sizing analyses are contained in Figures F-12 and F-13 respectively.

In general, the cold gas systems are the heaviest. However, the oxygen system could be integrated with the PLSS O_2 tankage and would thus not require a separate tank. A freon boil-off system, on the other hand, does provide a higher impulse than cold gas for the same size system. Hydrazine systems offer the highest impulse for a given size but the thermal and toxicity effects of hydrazine must be considered. A water/hydrazine mixture system minimizes the thermal effects at the expense of impulse.

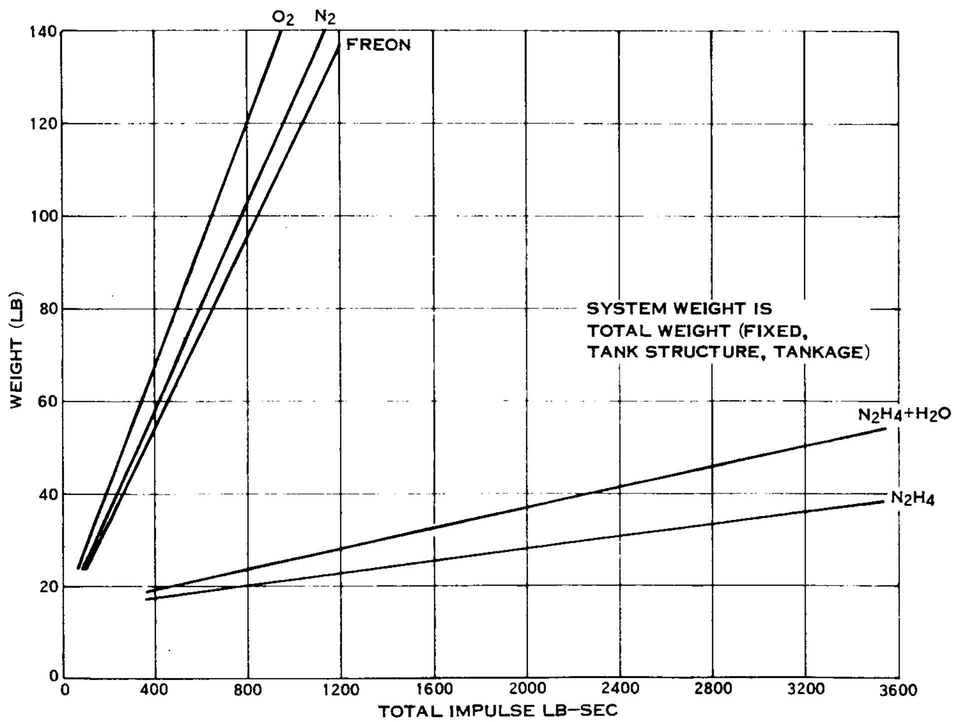

FIGURE F-12. SYSTEM WEIGHT VS TOTAL IMPULSE

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2.2.2.3 System Comparison (Continued)

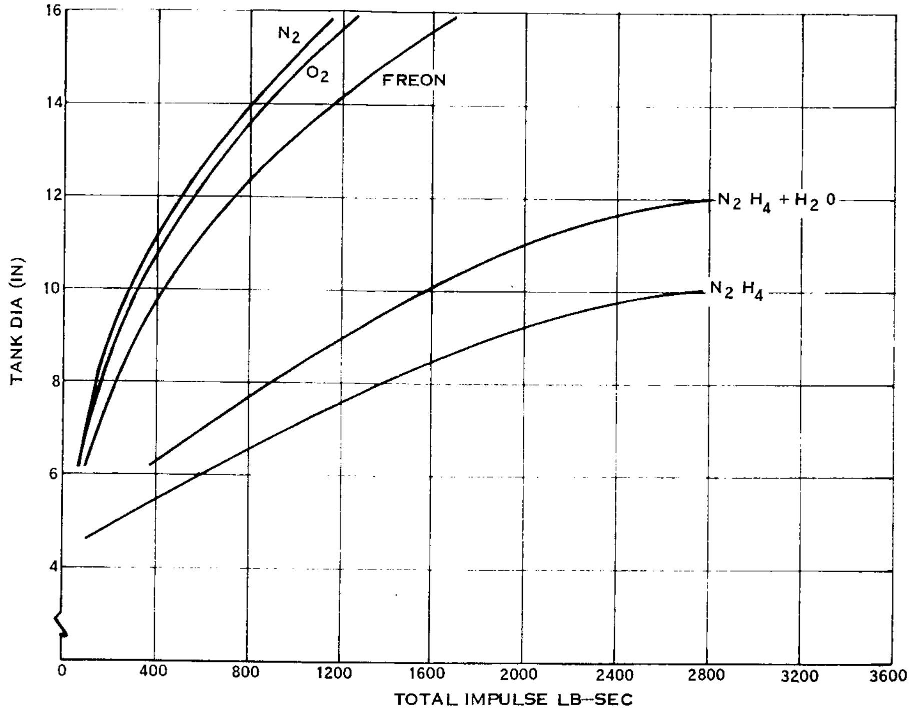

FIGURE F–13. TANK DIAMETER VS TOTAL IMPULSE

In preparing these trade-offs, titanium spherical tanks were assumed for all systems except the oxygen system where a stainless steel tank was utilized because of O_2/titanium material compatibility problems. Tankage weights were based on 4000 psi operating pressure for cold gas and freon systems (8000 psi burst) and 400 psi operation for the hydrazine systems (800 psi burst). Total weights other than tankage were assumed as follows:

	Hydrazine Systems	Other Systems
Regulator	--	1.5#
Fill & Drain Connectors	0.3#	0.15#
Filter	0.2#	0.2#
Instrumentation	1.0#	1.0#
Controls	3.0#	3.0#
Thruster Valves	3.6#	3.6#
Wire/Plumbing	2.3#	2.3#
Thrusters	1.5#	0.5#
Structure*	2.4#	2.5#
	14.3#	14.75#

* Does not include tankage structure.

2.2.2.4 Other Considerations

Aside from the weight and volume trade-offs presented previously, other factors such as power, contamination, safety, plume temperature, thermal control and development cost must be considered. These aspects are discussed in the following sections.

Power

The main power required by all systems studied is for operation of the electrical valves for each thruster. This power is about the same for each system and is approximately 6 watts per valve. Considering a maximum of 6 valves operating at any one time, a total of 36 watts is required. The hydrazine systems would additionally require 10-15 watts of power for thermal control to prevent freezeup. Boil-off systems also require thermal control to eliminate thermal expansion characteristics.

Contamination

The freon and cold gas systems do not pose any significant contamination problems in space. The products of combustion from a pure hydrazine system are nitrogen, hydrogen and ammonia. None of these products should present a space contamination problem unless they condense on a cold surface. This condensation problem, however, is no worse than oxygen or nitrogen condensation resulting from cold gas system expulsions. The hydrazine system also expels about 2% water which could present problems. A hydrazine and water mixture system on the other hand does pose a contamination problem due to the large quantities of water expelled. Condensation of this water on radiators, lenses, etc., must be avoided. Possibly a cold gas system in conjunction with the hydrazine and water system would be required for maneuvering in the proximity of sensitive equipment.

Safety

A hydrazine system presents a more significant safety problem than cold gas and freon boil-off systems primarily because of its toxicity hazards. Thus, reasonable precautions must be exercised to assure crew safety. With reasonable precautions, the handling of a hydrazine system should present no serious hazard.

2.2.2.4 Other Considerations (Continued)

Plume Temperature

The cold gas and freon boil-off systems do not present any plume impingement temperature problems. Impingement from the hydrazine systems exhaust, however, must be considered thermally. The water and hydrazine combination minimizes such a problem and is the main reason it was selected for evaluation. The pure hydrazine system has hot gas exhaust and care must be taken to prevent direct, lose exhaust on the suit. The thruster arrangement shown in Figure precludes such impingement and was selected for this reason. If thrusters are mounted closer to the body, shields must be provided to protect against plume impingement.

Thermal Control

Thermal control is not required with the cold gas systems but is necessary with the freon and hydrazine concepts. The freon tankage requires thermal control to avoid thermal expansion/contraction effects resulting from space temperature excursions. Approximately 10-15 watts is required for such control. The hydrazine systems require control to both avoid freeze-up and prevent excessive heat transfer to the astronauts during firing. The heat transfer during firing can be controlled by designing for good radiation capabilities. Freeze-up during non-firing periods can be avoided by including electrical heaters. The power required for such devices is approximately 10-15 watts for the system sizes studied.

Development Cost

The development costs for all systems studied would be approximately the same. The fact that the design requirements for a back-mounted propulsion system are well within the state of the art for each system studied eliminates any development risk costs.

2.2.2.5 Summary

Various self-powered propulsion systems were analyzed for use in an EV astronaut translation device. As a result of the analyses and pertinent issues presented in this report, it appears that a pure hydrazine system is the most attractive approach for total impulse levels above 1000 lb-seconds.

2.2.2.5 Summary (Continued)

This determination is based primarily on the weight and size advantages of this system as well as the penalties for thermal control and the tank heating required. The hydrazine and water system does reduce the thermal control necessary with pure hydrazine, however, the associated weight and size increase coupled with potential contamination from the water exhaust makes this system less desirable.

For total impulse levels in the range of 500 to 1000 lb-seconds, a pure hydrazine system still has a weight and size advantage over a cold gas or freon system. This advantage is not as significant as for total impulses greater than 1000 lb-seconds and the penalties for thermal control reservoir heating as well as safety and contamination considerations significantly reduce the weight and size advantage. A hydrazine system, however, may still be preferred provided these potential problem areas can be easily resolved.

2.3 Maneuverable Work Platform

A maneuverable work platform (MWP) provides an excellent means of Astronaut translation to various worksites. Such a device if suitably anchored could serve as a work station. It could also be equipped with life support, payload carrying space, and navigation equipment as well as a propulsion system. Carrying of life support equipment would preclude the need to mount this system on the back of the astronaut and thus give him more freedom for working. This platform could provide for translation distances in the order of miles, whereas a back-mounted unit is limited to distances of the order of less than 500 feet due to propellant quantities required and the mass of a navigation system.

The MWP consists of four basic elements:

a. A forward control module shown in Figure F-14.

b. An aft module.

c. A removable tools/spares module.

d. A collapsible cargo frame.

2.3 Maneuverable Work Platform (Continued)

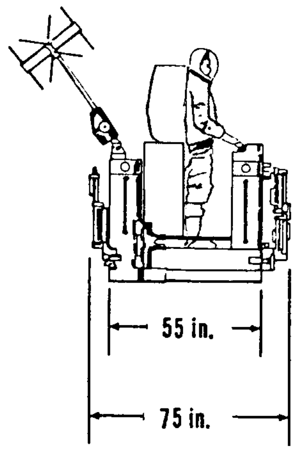

FIGURE F-14. MANEUVERABLE WORK PLATFORM--RETRACTED CONFIGURATION

These four elements allow the MWP to take on three basic configurations:

a. A fore and aft module just for astronaut maneuvering.

b. A fore, aft and tool module which serves a work platform and maneuvering device.

c. All four modules providing a work station, a maneuvering unit and a cargo carrier as shown in Figure F-15.

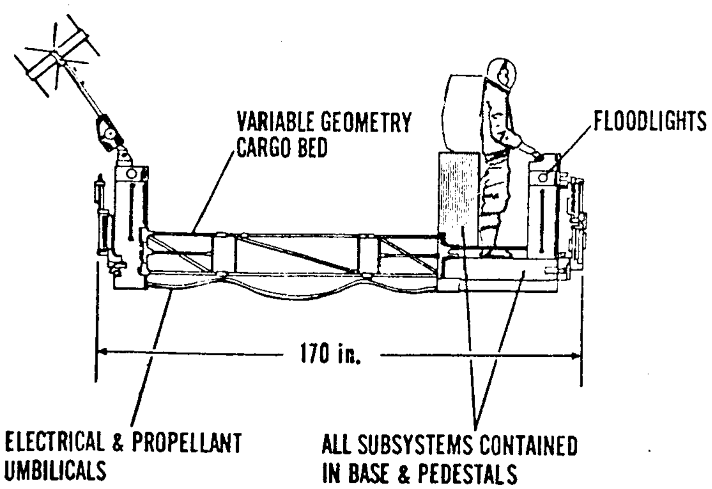

FIGURE F-15. MANEUVERABLE WORK PLATFORM--EXTENDED CONFIGURATION

2.3 Maneuverable Work Platform (Continued)

Available MWP performance requirements are listed in Table F-12.

MANEUVERABLE WORK PLATFORM PERFORMANCE REQUIREMENTS	
WEIGHT (LBS)	1600
VOLUME (FT^3)	140
DIMENSIONS (FT)	5 X 4 X 7
SUPPORT EQUIPMENT WEIGHT* (LBS)	2006
SUPPORT EQUIPMENT VOLUME* (FT^3)	186
PROPELLANT, GAS	OXYGEN
POWER (WATTS)	580 (980 PEAK)
DATA REQUIREMENTS (BITS/SEC)	8000 (5000 MIN.)
•VOICE	YES
•TV FILM	YES

*INCLUDES WEIGHT AND VOLUME FOR AMM, TELEOPERATOR SYSTEM, CAMERA AND DATA DISPLAYS.

TABLE F-12. MANEUVERABLE WORK PLATFORM PERFORMANCE REQUIREMENTS

As can be seen from this table, the estimated weight for such a platform is 1600 pounds -- a significant weight. This weight penalty coupled with the fact that during the 1979-1990 time frame, maneuvering distances are estimated at less th than 500 feet with payloads less than 100 pounds, makes the platform unfeasible at the present time. Should translation distances or mass transport requirements increase significantly, the work platform concept would become an attractive candidate for astronaut and cargo translation. A summary of advantages and disadvantages associated with the MWP are listed in Table F-13.

ADVANTAGES	DISADVANTAGES
RANGE IN THE ORDER OF MILES	HEAVY, EXPENSIVE, COMPLEX
NO CUMBERSOME BACK-MOUNTED EQUIPMENT NEEDED	REQUIRES TRANSLATION TO PLATFORM TO BOARD
CARGO CARRYING CAPABILITY	MISSION REQUIREMENTS DO NOT DICTATE NEED
SERVES AS TRANSLATION AID AND WORK PLATFORM	

TABLE F-13. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF MANEUVERABLE WORK PLATFORM

2.4 Summary

Three basic powered maneuvering concepts (hand-held, back-mounted, and platform mounted) have been presented. The back-mounted device was selected for the Shuttle EVA powered maneuvering requirements based on its compatibility with both the potential tasks and the performance necessary. The potential tasks identified involve contingency astronaut rescue operations from a disabled Shuttle (approximately 500 lb-second total impulse). The requirements for these type of operations eliminate the need for powered platforms which are more efficient for longer range (higher total impulse) translations. The hand-held maneuvering devices were eliminated due to stability problems associated with their performance.

APPENDIX G

SPACE TOOLS

1.0 SPACE TOOLS

Various tools have been developed for space applications and an overview of the current tool development technology reveals that the following classifications encompass all tools that might be utilized for Shuttle EVA/IVA task performance.

a. Bonding and Electroadhesor Tools

b. Cutting Tools

c. Hammers

d. Gas Leak, Pressure Detection and Measurement Tools

e. Electrical and Electronic Maintenance Tools

f. Tool Kits and Sets

g. Screwdriving and Torquing Tools

h. Tube Connector Tools

i. Welders

The following sections expand on each classification describing specific tools and their performance characteristics.

2.0 BONDING AND ELECTROADHESOR TOOLS

Bonding and Electroadhesor tools provide a quick connect and disconnect capability which do not damage the surface on which they are applied. These attachment techniques are applicable for fabrication and maintenance in space and as worksite and translation restraints. Specific tools included in this category as well as performance characteristics are contained in Table G-1.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
BONDING & ELECTROADHESOR TOOLS			
A. EXOTHERMIC SPACE BONDING SYSTEM	3 X 4.75" X 10.25"	5 LBS.	POWER REQUIREMENTS: 6 VDC NICKEL CADIUM CELL HAND TRANSPORTABLE TO SITE BONDS TO 123# TENSILE STRENGTH ON ALUMINUM WORKS POORLY ON METAL THICKNESSES BELOW .012" METAL MUST BE PREHEATED TO 200°F BEFORE BONDING OCCURS
B. EXTRAVEHICULAR SPACE ADHESIVE SYSTEM	4.56" X 1.5" DIA.	5 LBS.	2-5# FORCE MUST BE MANUALLY APPLIED (COMPRESSION) TENSILE STRENGTH 69# IN 0 TO 250°F TEMPERATURE OPERATES IN VACUUM UP TO 10^{-6} TORR MAXIMUM LIFE OBTAINED WHEN STORED AT 40°F MANUALLY OPERATED (TOTALLY) HAND TRANSPORTABLE TO SITE LOW RESISTANCE TO PEELING FORCES
C. FLEXIBLE PROTOTYPE (SINGLE-POLE) ELECTROADHESOR	1" X 4" DIA.	5 LBS.	BONDS TO 2# TENSILE AND 1# SHEAR SHEAR STRENGTH REQUIRES 8.4 VDC (MALLORY TR-126T2) BATTERY 30-40 HR. BATTERY LIFE (INTERMITTENT OPERATION) HAND TRANSPORTABLE TO SITE LOW RESISTANCE TO PEELING FORCES
D. HAND MODEL PROTOTYPE (SINGLE-POLE) ELECTROADHESOR	10" X 7" x 5" DIA.	5 LBS.	BONDS TO 6# TENSILE AND 40# SHEAR LOADS REQUIRES 8.4 VDC BATTERY (MALLORY TR-126T2) LOW BOND RESISTANCE TO PEELING FORCES OPERATES ON ELECTRO-CONDUCTING SURFACES ONLY 30-40 HR. BATTERY LIFE (INTERMITTENT USE) HAND TRANSPORTABLE TO WORK SITE TOOL ITSELF IS THE BONDED HARDWARE (FOR USE AS HANDHOLD, ETC.) MUST BE USED ON CLEAN SMOOTH SURFACES
E. HAND MODEL (TWO-POLE) ELECTROADHESOR	UNKNOWN	2.5 LBS.	SAME AS D. ABOVE EXCEPT AS NOTED: BONDS TO ACCEPT 3# TENSILE AND 18# SHEAR LOADS
F. RESTRAINT BUTTONS AND APPLICATOR	7" X 3" x 8"	0.75 LBS.	WITHSTANDS LOADS 50# WHEN BONDING TEMPERATURE = 450°F 11-90 SEC. REQUIRED TO REACH BONDING TEMPERATURE WITH ALUMINUM SHEETS VARYING FROM 0.015" TO 0.100" AND VARIOUS INITIAL TEMPERATURES FROM 160°F TO 70°F POWER SOURCE: 12 V YARDNEY HR-15 SILVER-ZINC BATTERY
G. STUD BONDING TOOL	UNKNOWN	2.5 LBS.	STUD HEATED TO AS MUCH AS 707°F IN 30 SEC. STUD CANNOT BE RELEASED UNLESS STUD IS APPLIED PERPENDICULAR TO THE SURFACE TO BE BONDED HOLDS UP TO 500# PERPENDICULAR TO THE BOND LINE AT ROOM TEMPERATURE POWER SOURCE: 28V, 1KW

TABLE G-1. BONDING AND ELECTROADHESOR TOOLS

3.0 CUTTING TOOLS

Cutting tools are required for such diversified in space tasks as drilling, metal cutting, cable cutting, etc. Such tools provide for on-the-spot cutting and fitting and as such, significantly expand the scope of EVA/IVA operations. A listing of tools encompassed by this category as well as performance characteristics of the tools are listed in Table G-2.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
CUTTING TOOLS			
A. POWER DRILL	8.25" X 3.25"	3.5 LBS	DRILLS HOLES 1/4" TO 21/32" DIAMETER IN 0.040" 7075-T6 ALUMINUM AND 028 6-4 TITANIUM IN LESS THAN 34 SEC. FORCE REQUIRED BY ASTRONAUT: 0.5 LB.-SEC. TO INITIATE NEEDLE PENETRATION NEEDLE TRAVEL AND THUS WORKPIECE THICKNESS IS LIMITED TO 3/16" POWER SOURCE: MOTOR/HANDLE ASSEMBLY PROVIDES THE MECHANICAL POWER TO DRIVE THE DRILL
B. POWER SAW	8" X 2.5" X 4"	3 LBS.	NO OPERATOR FORCES NEEDED OTHER THAN MINOR STEERING CUTS AT RATES FROM 4 FT./MIN. IN 0.016" 7075-T6 ALUMINUM POWER SOURCE: MOTOR/HANDLES ASSEMBLY PROVIDES THE MECHANICAL POWER TO DRIVE THE SAW
C. WINDOW SAW CUTTING TOOL	7" X 6" X 14"	14 LBS.	OPERATES SATISFACTORILY UNDER EARTH AMBIENT CONDITIONS CAPABLE OF CUTTING A HOLE IN 1/8" 2014-T6 ALUMINUM PLATE IN 32 SEC. POWER SOURCE: COMPRESSED AIR SUPPLY AT 3,000 PSI CONTAINED IN A 7" SPHERE 55-TOOTH CYLINDRICAL CUTTING BLADE DRIVEN AT 0.667 RPS CUTTING RATE: 0.005" PER REVOLUTION

TABLE G—2. CUTTING TOOLS

4.0 HAMMERS

Hammers offer a wide range of EVA/IVA task capabilities from driving fasteners and cutting tools to metal shaping activities. They can be used to free stuck parts or to position tight fitting components. Two basic hammer types, hand operated and gas driven, have been developed. Table G-3 below lists these hammer concepts along with performance characteristics of each.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
HAMMERS			
A. DEAD BLOW HAMMER	12.5" X 1.5" X 4.3"	1.75 LBS.	POWER SOURCE: MANUALLY OPERATED HAMMERING TASK BEST ACCOMPLISHED BY USING SHORT, SWIFT BLOWS AND GRIPPING HANDHOLD
B. WINCHESTER SPACE TOOL	6" X 2"	7.68 LBS.	UP TO 140 FT.-LBS. OF ENERGY CAN BE DELIVERED TO THE WORK PIECE POWER SOURCE: MODIFIED 22 CALIBER HORNET CARTRIDGES

TABLE G-3. HAMMERS

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5.0 GAS LEAK, PRESSURE DETECTION AND MEASUREMENT TOOLS

Small portable tools capable of measuring gas pressure and detecting and measuring fluid leaks are required to locate and quantify such possible malfunctions. Such leakage could develop in the space structure's skin, joints, pipes or tubing due to faulty construction, meteorite damage or stresses. Table G-4 below lists performance characteristics of two concepts for leakage detection and measurement.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
GAS LEAK AND PRESSURE DETECTION TOOLS			
A. MASS FLOWMETER	12.5" X 9.25" X 8.5"	7.75 LBS	MEASURES FLOW RATE OF LEAKING GASES USE RESTRICTED TO OUTER SPACE SINGLE CREWMEMBER OPERATED INTERNAL POWER SUPPLY - 9 V BATTERY INCLUDES SEVERAL ATTACHMENTS TO ENHANCE TOOL APPLICABILITY MEETS PERFORMANCE REQUIREMENTS THAT THE METER SHOULD MEASURE, WITHIN 90 SEC., A LEAK OF 0.006 TO 0.67 STAND. IN.^{3}/SEC. IN A PRESSURE ENVIRONMENT OF 1.93 X 10^{-5} TO 1.33 X 10^{-15} PSI WITH AN ERROR NOT TO EXCEED 5%
B. PILOT MODEL LEAK DETECTOR	8.3" X 8.3" X 7.8"	6.3 LBS.	SELF-CONTAINED POWER SUPPLY (28 V BATTERY) MEASURES GAS LEAKS ONE-HANDED OPERATION MEASURES PRESSURES FROM 10^{-10} TO 10^{-4} TORR DETECTS LEAKS 6.17 X 10^{-8} STAND. IN.^{3}/SEC.

TABLE G–4. GAS LEAK AND PRESSURE DETECTION TOOLS

6.0 ELECTRICAL AND ELECTRONIC MAINTENANCE EQUIPMENT

Scheduled and unscheduled maintenance and repairs of electrical equipment can be achieved with the proper selection of tools. Basically, tools permitting squeezing, holding and positioning of electrical connections are required. In addition, were strippers, cutters, and crimpers are necessary for removing insulation and cutting and joining wires. Concepts developed for such maintenance are listed in Table G-5 below along with performance characteristics of each.

TOOL CATEGORY	SIZE/VOLUME	PERFORMANCE CHARACTERISTICS
ELECTRICAL/ELECTRONIC TOOLS		
A. COAXIAL CABLE CUTTERS	LENGTH 6"	MANUALLY OPERATED
B. MULTIPURPOSE HAND WIRING TOOL	UNKNOWN	MANUALLY OPERATED FUNCTIONS AS PLIERS, WIRE STRIPPERS WIRE CUTTER AND WIRE CRIMPER
C. PROGRAM CONTROL CARD EXTRACTOR SYSTEM	7" X 7" X 1.5"	MANUALLY OPERATED

TABLE G—5. ELECTRICAL/ELECTRONIC TOOLS

7.0 TOOL KITS AND SETS

A general purpose tool set is useful in providing an astronaut with the ability of performing a wide range of tasks. The set can be small and portable such that it can be easily carried by an astronaut to any worksite. Two such sets previously developed are presented in Table G-6 along with the contents of each set.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
TOOL KITS AND SETS			
A. CREWMAN INFLIGHT TOOL SET	UNKNOWN	2.88 LBS.	INCLUDES FOLLOWING ITEMS COVERED ELSEWHERE APOLLO TORQUE WRENCH APOLLO T-HANDLE APOLLO ADJUSTABLE WRENCH
B. MARTIN SPACE TOOL KITS	9.5" X 14.5" X 14.5"	38 LBS.	INCLUDES 12V DC BATTERY PACK 163 WATT-HOURS @ 40 AMP DEAD BLOW HAMMER MOTOR/HANDLE ASSEMBLY POWER DRILL SCREWDRIVER RATCHET HANDLE WORKLIGHTS POWER IMPACT WRENCH POWER SAW RESTRAINT BUTTONS & APPLICATOR SMALL PARTS HOLDER/MANIPULATOR

TABLE G-6. TOOL KITS AND SETS

8.0

SCREWDRIVING AND TORQUING TOOLS

There are many assembly, fabrication and repair tasks that require the application of torque. Among these are the installation or removal of nuts, bolts, screws, fittings, etc., the adjustment of valves, the alignment of hardware parts and rotary drive mechanism. Many of the tools included in this category were developed to reduce reactive torque to the operator and to permit rapid nut/bolt running operations. Table G-7 presents tools in this category and performance characteristics for these tools.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
SCREWDRIVING AND TORQUING TOOLS			
A. AERO JET SPACE BOLT REMOVAL TOOL	4.25"X10.75"X20.32"	19 LBS.	RETRACTION UNIT EQUIPPED WITH A SOCKET SIZED FOR 5/16", 12-POINT HEAD BOLTS RIGHT ANGLE DRIVE TRANSMITS TORQUE AROUND CORNERS REMOVES BOLTS TORQUED TO 145-155 IN.-LBS. POWER SOURCE: 12 VDC
B. APOLLO ADJUSTABLE END WRENCH	10"X2"	2 LBS.	JAWS ADJUSTABLE TO ANY SIZE BETWEEN 3/8" TO 1" JAWS LOCK INTO POSITION WHEN TORQUE IS APPLIED MANUALLY OPERATED
C. APOLLO IN-FLIGHT MAINTENANCE TOOL	5.32"X3.38"	5 LBS.	EQUIPPED WITH 22.12", 13.62", AND 4.00" LENGTH MALE HEXAGONAL WRENCH ATTACHMENTS LOOSENS AND TIGHTENS CLAMPS, MOUNTING BOLTS, AND CALFAX FASTENERS EQUIPPED WITH CARD EXTRACTOR MANUALLY OPERATED
D. APOLLO T-HANDLE	2.1"X3.11"	5 LBS.	3/8" BALL LOCK AND 5/32" MALE HEXAGONAL WRENCH TIP LOCATED AT BOTTOM OF DRIVE SHAFT MANUALLY OPERATED
E. APOLLO TORQUE WRENCH	6.25"X1.5"X0.75"	5 LBS.	TORQUE CAN BE PRE-SET BY ROTATING HANDLE IN UNIT TURNS OF 180° TORQUE RANGES: 50, 100, 150, AND 200 IN.-LBS. DRIVE END CONSISTS OF 7/16" AND 5/32" MALE HEXAGONAL WRENCH HEADS DIRECTION IN WHICH THE WRENCH RATCHETS CONTROLLED BY RATCHET LEVER MANUALLY OPERATED
F. BOEING TORQUE CANCELLING TOOL	22"X14"X3"	5 LBS.	REACTION FORCES ARE OPPOSED AND TEND TO CANCEL ONE ANOTHER VARIOUS SIZED SOCKETS CAN BE USED WITH TOOL MANUALLY OPERATED
G. BOLT INSTALLATION AND REMOVAL TOOL (BIRT)	15 1/2"X5"X3 1/8"	10 LBS.	IMPACTING CYCLE CAN BE SET FOR 0-30 SEC. WITH 5/16" SOCKET, 140-200 IN.-LBS. TORQUE CAN BE PRODUCED IN 5 SEC. ON BOLT #MS21250H05004 WITH 1/2" SOCKET, 700-950 IN.-LBS. TORQUE CAN BE PRODUCED IN 5 SEC. ON BOLT #MS21250H08804 POWER SOURCE: EXTERNAL 12 VDC WITH 50 AMP. CURRENT CAPACITY EQUIPPED WITH 1/4", 5/16", 3/8", 7/16", AND 1/2" SOCKET ASSEMBLIES
H. INERTIA WHEEL	13"X9.5"	5 LBS.	3/8" SQUARE DRIVE LOCATED ON DRIVE SHAFT LOW AMOUNT OF ROTATIONAL MOTION REQUIRED FOR OPERATION MANUALLY OPERATED VARIOUS SIZED SOCKETS CAN BE USED WITH TOOL
I. MOTOR/HANDLE ASSEMBLY	7.0"X3.0"X3.0"	5 5/8 LBS.	EASILY TRANSPORTABLE TO WORKSITE DIFFICULT TO ATTACH OR REMOVE SEPARATELY CONTAINED 12 VDC BATTERY
J. NUT & BOLT WRENCH (NAB)	UNKNOWN	UNKNOWN	NO DATA EXISTS SERVES AS RATCHETING NON-TORQUE CANCELLING TWO-HAND HELD TOOL
K. OPEN END FLAT RATCHET WRENCH	17"X.6"X6"	3 LBS.	MANUALLY OPERATED EASILY TRANSPORTED TO WORKSITE CAN ENGAGE NUT OR BOLT IN 15° INCREMENTS ABOUT FULL 360° OF SHANK CAN WITHSTAND 660 IN.-LBS. TORQUE HUMAN OPERATOR CAN APPLY 75 IN.-LBS. WITH HAND SQUEEZE WILL FIT 1/2" BOLTS WILL ACCEPT BOLT DRIVES OF VARIOUS SIZES
L. PLIERS-WRENCH (PLENCH)	UNKNOWN	UNKNOWN	MANUALLY OPERATED MULTIPLE SOCKET VERSATILITY HAND SQUEEZE OPERATED
M. POWER IMPACT WRENCH	6.4"X2 1/4" DIA.	2 5/8 LBS.	REQUIRES COUPLING TO MOTOR HANDLE ASSEMBLY (DESCRIBED ELSEWHERE) ACCEPTS 5 1/2" DRIVE SOCKETS MAXIMUM TORQUE 85 FT.-LBS. IN 3 SEC. MAXIMUM HANDLE TORQUE REACTANCE REQUIREMENTS 5.6 IN.-OZS. CREW TRANSPORTABLE TO WORKSITE
N. RATCHET HAND TOOL	UNKNOWN	.2 LBS.	HAND OPERATION, NON-TORQUE CANCELLING NUT & BOLT RATCHET CREW TRANSPORTABLE TO WORKSITE
O. SCREWDRIVER RATCHET HANDLE	4.6"X1.4"X2.7"	.75 LBS.	MANUALLY OPERATED, NON-TORQUE CANCELLING CREW TRANSPORTABLE TO WORKSITE USES STANDARD 1/4" DRIVE ACCESSORIES
P. SPACE POWER TOOL SYSTEM	10 13/16"X4 1/2"X5"	7.62 LBS.	INTERNAL POWER SUPPLY (BATTERY) CREW TRANSPORTABLE TO WORKSITE SELF-CONTAINED WORK AREAS ILLUMINATING TORQUE OUTPUT = 45 FT.-LBS. ON 1/2" BOLT IMPACT DRIVER
Q. SPACE TOOL MITTEN	16.4"X5"X8.1"	9.7 LBS.	SELF-CONTAINED POWER SUPPLY (BATTERY) DELIVERS 200 IN.-LBS. TO 1/2" FASTENER PROVIDES SUITED GLOVE PROTECTION ACCEPTS STANDARD 1/4" DRIVE IMPACT DRIVER CREW TRANSPORTABLE TO WORKSITE
R. SPIN TORQUE SPACE TOOL	16 3/4"X2"X11"	6 LBS.	EITHER MANUALLY OR ELECTRICALLY DRIVEN BATTERY LIFE EXPECTANCY - 1 HOUR NON-TORQUE CANCELLING TWO-HANDED OPERATION STANDARD 3/8" DRIVE CREW TRANSPORTABLE TO WORKSITE
S. SPIRAL DRIVE SCREWDRIVER	UNKNOWN	UNKNOWN	1/4" DRIVE INSIGNIFICANT OUTPUT FOR REQUIRED INPUT MANUALLY OPERATED CREW TRANSPORTABLE
T. ZERO REACTION SPACE WRENCH	UNKNOWN	UNKNOWN	MANUALLY HAND SQUEEZE OPERATED TORQUE CANCELLING CREW TRANSPORTABLE

TABLE G-7. SCREWDRIVING AND TORQUING TOOLS

9.0 TUBE CONNECTION TOOLS

Provision for repair and maintenance of the many fluid lines that are used on the shuttle is required, since they may suffer damage from stresses and vibrations. Other than equipping the shuttle with spare tubing, the only basic task in the fabrication and repair of this tubing is in the connection of sections. In Table G-8 below, some of the tools that have been developed to perform this task are listed along with their performance characteristics.

TOOL CATEGORY	PERFORMANCE CHARACTERISTICS
TUBE CONNECTION TOOLS	
A. SEMIREMOTE SPUNFIT WRENCH	MANUALLY OPERATED SCISSOR MOTION (TWO ARMS) CREW TRANSPORTABLE
B. SPUNFIT WRENCH	FOR USE ON HEXAGONAL HEAD CONNECTORS MANUALLY OPERATED CREW TRANSPORTABLE
C. TUBE SWAGING DEVICE	POWERED BY 22 CALIBER BLANK CARTRIDGE RESTRICTED USAGE CREW TRANSPORTABLE TO WORKSITE

TABLE G-8. TUBE CONNECTION TOOLS

10.0 WELDERS

In-space welding has generally been considered for the structural leakage maintenance of long flight duration vehicles. This is primarily due to the fact that welding provides the most positive, lasting joint. The relatively short duration of the shuttle flights (7 days) does not justify such a need for structural repairs. If, however, certain experiments require the use of in-space welding, the following Table G-9 presents concepts that have been developed to date along with their performance characteristics.

TOOL CATEGORY	SIZE/VOLUME	WEIGHT	PERFORMANCE CHARACTERISTICS
WELDERS			
A. HAND HELD ELECTRON BEAM GUN	3.5" DIA. X 10"	10 LBS	WELDS 15 IN./MIN. IN ALUMINUM-TITANIUM-STAINLESS UP TO .125" THICK NEEDS 20 KV AT 150 MA POWER SUPPLY
B. MATERIALS JOINING TOOL	6.0" X 2" X 3"	9.5 LBS	EXTERNAL POWER SOURCE NEEDS 7.5 KV AT 300 MA POWER SUPPLY MUST BE USED IN VICINITY OF POWER SUPPLY SPOT WELDS ACCEPTABLE IN MATERIALS UP TO .06" THICK CIRCULAR WELDS ON TUBING UP TO .4" DIA. WERE SATISFACTORY ON STAINLESS, COPPER, TITANIUM UNSATISFACTORY PERFORMANCE ON ALUMINUM
C. PLASMA ELECTRON BEAM WELDER	UNKNOWN	UNKNOWN	EXTERNAL POWER SOURCE REQUIREMENT 10V @ 2 KW WELDS TO 1/4" THICK 6061 ALUMINUM WELDING RATE UP TO 20 IN./MIN. INTERNAL POWER SUPPLY (BATTERY) CREW TRANSPORTABLE TO WORKSITE
D. PORTABLE ELECTRON BEAM WELDER (0.5 KW)	14" LONG X 13" DIA.	45 LBS.	SELF-CONTAINED POWER SUPPLY (BATTERY) CREW TRANSPORTABLE TO WORKSITE SHORT BATTERY LIFE
E. WESTINGHOUSE ELECTRON BEAM WELDER	21" X 12" X 10"	61 LBS	INTERNAL/EXTERNAL POWER SUPPLY (BATTERY) 35V DC - 70 AMP REQUIREMENTS WELDS 1/8" 18-8 STAINLESS AT 37 IN./MIN. X-RAY SHIELDING MUST BE PROVIDED CREW TRANSPORTABLE TO WORKSITE

TABLE G—9. WELDERS

APPENDIX H

EVA SYSTEM MINI-SPECIFICATION

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

DESIGN AND PERFORMANCE SPECIFICATION

FOR

SHUTTLE EXTRAVEHICULAR SYSTEM

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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1.0 SCOPE

This specification defines the baseline performance and interface requirements of the EVA system to be used for performance of EVA tasks associated with the Space Shuttle Program.

1.1 System Description

The EVA system consists of an anthropomorphic pressure suit, a primary life support system, an emergency life support system and supporting equipment which permit a crewman to perform EVA tasks.

2.0 APPLICABLE DOCUMENTS

The following documents, of exact revision shown, form a part of this specification to the extent specified herein.

2.1 Specifications

NASA

MSC/IESD 19-3 Rev. A	Interference Control Requirements, Aerospace Equipment
PF-SPEC-1	CM/LM Potable Water Specification

Federal

FED-STD-209	Clean Room and Work Station Requirements, Controlled Environment

Military

MIL-O-27210B	Oxygen, Aviators Breathing, Liquid and Gas
MIL-D-1000	Drawings, Engineering and Associated Lists
MIL-P-6906	Plates, Information and Identification
MIL-C-6021E	Castings, Classification and Inspection of
MIL-W-22248	Weldments, Aluminum and Aluminum Alloys
MIL-A-8625	Anodic Coatings, For Aluminum and Aluminum Alloys
MIL-A-5541	Chemicals, Films and Chemical Film Materials For Aluminum and Aluminum Alloys

2.2 Standards

MIL-STD-100A	Engineering Drawing Practices
MIL-STD-143A	Specification of Standards, Order of Precedence for the Selection of
MIL-STD-202B	Test Methods for Electronic and Electrical Component Parts
MS 33586	Metals, Definition of Dissimilar
MSFC-STD-181	Finishes and Coatings for Corrosion Protection of Space Vehicle Structures and Associated Equipment, Standard for

2.3 Bulletins

ANA Bulletin 438C	Age Control for Synthetic Rubber Parts
ABA Bulletin 445 with MSC Supplement 1	Engineering Changes to Weapons, Systems, Equipment and Facilities

2.4 Other Publications

NASA

MSC-PA-D-67-13	Apollo Spacecraft Non-Metallic Material Requirements
NHB5300.4 (1B)	Quality Program Provisions for Aeronautical and Space System Contractors
NPC250-1	Reliability Program Provisions for Space System Contractors
MSC-A-D-66-7	Parts Reliability Program Requirements
ASPO-RQA-11A	Qualification Test Program Guidelines
MSCM-5312	Reliability and Quality Assurance Manual
NASA-SP-8013	Meteoroid Environment Model - 1969 (Near Earth to Lunar Surface)
ASPO-RQTD-67-1	Reliability, Quality and Test Requirements for Government Furnished Equipment

Industry

USAS B46.1-62	Surface Texture, Surface Roughness, Waviness and Lay

3.0 REQUIREMENTS

3.1 Performance

The EVA system shall provide the crewman with the protection, mobility and life support for performance of EVA tasks which include:

a. Operation of instrumentation.

b. Replacement and repositioning of antennae.

c. Repair and replacement of thruster modules.

d. Operation and servicing of free flying maneuvering units.

e. Repair, replacement, calibration and inspection of modular equipment and instrumentation.

f. Cleaning of optical and radiator surfaces.

g. Connection, disconnection and stowage of fluid and electrical umbilicals.

h. Inspection and photography of vehicle and payload systems, mechanisms and components.

i. Installation, removal and transfer of film cassettes, material samples, protective covers and instrumentation.

j. Operation of equipment including assembly tools, cameras, and cleaning devices.

k. Translation to and from worksites, attachment and release of crewman restraints, equipment restraints, and attachment of tethers to crewman and spacecraft.

An EVA duration of four (4) hours is required for performing the various tasks of the majority of the flights.

3.1.1 Crewman Performance

3.1.1.1 Mobility

The required mobility ranges and torque levels for performance of EVA tasks are specified in Figure 1.

3.1.1.2 Visibility

The pressure suit helmet with extravehicular visors shall provide the crewman with an unrestricted field of vision as specified below:

a. Horizontal Plane - 120° left and 120° right

b. Vertical Plane - 90° up and 105° down

The helmet and extravehicular visor requirements of the Apollo Space Program are adequate for the Shuttle EVA system.

3.1.1.3 Crewman Protection

The EVA/IVA system shall provide the crewman with pressure, thermal, and meteoroid protection as specified below.

3.1.1.3.1 Pressure Protection

The EVA system shall maintain the gas pressure on the crewman above 8.0 psia for all normal operational modes. The oxygen concentration of the crewman's breathing supply shall be compliant with the unimpaired performance zone of Figure 2.

3.1.1.3.2 Thermal Protection

The crewman shall be thermally protected such that direct skin contact with surface temperatures beyond the range of 39 to 105°F is avoided.

3.1.1.3.3 Meteoroid Protection

The crewman shall be protected from the free space meteoroid environment defined by NASA SP-8013 for a period of 16 hours per flight. The probability of penetration shall be 95%.

3.1.1.3.4 Impact Protection

The EVA system shall protect the crewman from impacts with payloads and spacecraft structures during EVA and airlock operation. The helmet of the pressure suit shall incorporate a head protection system to attenuate shock loads.

3.1.1.4 Communications

The EVA crewman shall be provided with two-way RF voice communications with the spacecraft crew members and another EVA/IVA crewman. A back-up, functionally independent system shall be incorporated to provide communications between the EVA crewman and the Orbiter. The communications system shall have a minimum range of 100 meters.

3.1.1.5 Waste Management

The system shall be capable of receiving and storing 1000 ccs of urine from the EVA crewman during a single EVA. Provisions shall be incorporated for transfer of the stored urine to the spacecraft waste management system with the cabin in a pressurized or depressurized mode.

3.1.1.6 Comfort

The EVA system shall provide the crewman with sufficient comfort for performance of the EVA tasks. The design of the equipment shall preclude discomfort through proper sizing and elimination of pressure points.

3.1.1.7 Thermal Storage

The crewman shall not be required to store more than 300 Btu during any EVA operating mode.

3.1.2 Life Support Requirements

The EVA system shall include a primary life support system (PLSS) for usage during normal operations. The PLSS shall be capable of satisfying the requirements specified herein with the crewman working at an average metabolic rate of 1000 Btu/hr for a period of four (4) hours with peak metabolic rates of 1500 Btu/hr for a maximum of ten (10) minutes. The PLSS shall satisfy the requirements of this specification for metabolic rates varying from 600 to 1500 Btu/hr for the duration of the EVA.

3.1.2.1 Breathing Oxygen Supply

The system shall store and deliver oxygen per MIL-0-27210B for the following usages:

	Quantity
Metabolic Consumption	.70 pounds
System Leakage	.07 pounds
Pressure Integrity Check	TBD
Instrumentation Error	TBD

The oxygen supply shall be capable of delivering oxygen at the maximum rates for metabolic consumption as defined by Figure 3 with a simultaneous maximum system leakage rate.

3.1.2.1.1 Oxygen Supply Recharging

The oxygen supply shall contain the oxygen specified in Paragraph 3.1.2.1 following recharge from the spacecraft 900 ± 20 psia supply.

Recharging shall be completed within 120 minutes and shall not require the use of tools.

3.1.2.2 Pressure Control

The PLSS shall control the gas pressure encompassing the crewman to 8.2 ± .2 psia with ambient pressure conditions of space vacuum.

3.1.2.2.1 Pressure Relief

The system shall incorporate pressure relief protection to prevent over pressurization of the pressure suit as a result of any single component or subsystem failure.

3.1.2.3 Contaminant Control

The PLSS shall be capable of controlling the level of CO_2, particulate, and trace contamination entering the pressure suit for the duration of each EVA.

3.1.2.3.1 CO_2 Control

The PLSS shall utilize lithium Hydroxide (LiOH) for removal of CO_2 produced metabolically as defined by Figure 3. The partial pressure of CO_2 entering the pressure suit shall not exceed the limits of Figure 4 when subjected to the metabolic profile of Figure 5. The LiOH may be replaced without the use of tools, prior to iniating subsequent EVA. Replacement LiOH shall be stored on board the spacecraft.

3.1.2.3.2 Particulate Contamination

The system shall limit the quantity of LiOH dust to 0.1 mg/m^3 of gas ventilating the pressure suit. In addition, the ventilating gas shall be filtered as required to assure proper system performance.

3.1.2.3.3 Trace Contamination

The PLSS shall incorporate activated charcoal to control the trace contaminants in accordance with Table I. The sources of trace contamination include the crewman and materials of the EVA system.

3.1.2.4 Thermal Control

The system shall provide sufficient thermal control capability to dissipate heat from the following:

Source	Amount
a. Metabolic Heat	4000 Btu
b. Environmental Heat Leak Inward	600 Btu
c. System Generated Heat	TBD

Thermal control shall be accomplished without reliance on outward environmental heat leaks or thermal storage by the crewman.

3.1.2.4.1 Control of Metabolic Heat

Metabolic heat shall be removed from the crewman by the circulation of a liquid coolant through a liquid cooling garment worn by the crewman. For maximum heat load conditions, the system shall be capable of supplying a liquid coolant

3.1.2.4.1 Control of Metabolic Heat- Continued

temperature of 45°F maximum at the inlet to the liquid cooling garment. For lesser heat load conditions, the system shall supply coolant temperatures ranging from 45 to 80°F to the liquid cooling garment. Inlet temperature shall be controlled manually by the crewman.

3.1.2.4.2 Environmental Heat Leaks

The system shall limit the average inward and outward heat leaks to ± 300 Btu/hr. Peak heat leak conditions shall not result in exceeding internal surface temperature limits specified in Paragraph 3.1.1.3.2.

3.1.2.4.2.1 Thermal Models

The EVA system shall satisfy the heat leak requirements of Paragraph 3.1.2.4.2 when subjected to the thermal models of Figure 6 for the duration of EVA. The system shall also be capable of alternating between the thermal models of Figure 6.

3.1.2.4.3 Heat Dissipation

The following operational modes of heat dissipation shall be utilized depending on the payload servicing mode.

Payload Servicing Mode	Mode
Extravehicular	Expendable water
Intravehicular	Coolant umbilical to spacecraft

The system shall be capable of satisfying the performance requirements of this specification while operating in either mode.

3.1.2.4.3.1 Expendable Water Mode

The expendable water mode of operation shall be considered the basic operating mode and shall dissipate heat loads through the sublimation or boiling of water in the vacuum environment. The system shall contain sufficient water to dissipate all system heat loads.

3.1.2.4.3.1 Expendable Water Mode -Continued

Prior to subsequent EVA, water supply shall be recharged without the use of tools from the spacecraft system.

3.1.2.4.3.2 Coolant Umbilical to Spacecraft Mode

The EVA system shall satisfy the requirements of this specification while operating with the spacecraft coolant umbilical system as defined by Paragraph 3.2.2.4.

3.1.2.4.4 Emergency EV Transfer

The PLSS shall be capable of providing life support to a crewman without a liquid cooling garment during an emergency crew transfer to a rescueing spacecraft. During this mode, the crewman metabolic rate is 800 Btu/hr for a maximum of one (1) hour. Crewman thermal storage is permitted.

3.1.2.5 Humidity Control

The ventilating gas entering the pressure suit shall have a dew point not greater than 50°F. Any water condensed shall be separated from the gas ventilation circuit. During the coolant umbilical to spacecraft operating mode, the separated water shall be contained within the system and delivered to spacecraft systems prior to conduct of subsequent EVA.

3.1.2.6 Ventilation

The system shall provide a ventilation gas flow for the removal of contaminants and humidity from the pressure suit. The temperature of ventilating gas entering the Pressure suit shall be within the limits of 50 to 90°F for all normal operating modes.

3.1.2.7 Emergency Life Support

A functionally independent life support system shall be incorporated to provide emergency life support in the event of a malfunction of the primary system. The emergency system shall be capable of operation independent of the primary system for a period of fifteen (15) minutes with a crewman metabolic rate of 1600 Btu/hour.

3.1.2.7 Emergency Life Support - Continued

Primary system failures requiring use of emergency system include:

a. Loss primary O_2 supply
b. Loss of pressure control
c. Loss of contaminant control
d. Loss of thermal control
e. Loss of humidity control
f. Loss of ventilation
g. Excessive system leakage

3.1.2.7.1 Oxygen Supply

The emergency system shall contain sufficient oxygen to satisfy the ventilation requirement of Paragraph 3.1.2.7.6 plus any oxygen required for pre-egress system check-out to be conducted at a maximum of six times per flight.

3.1.2.7.2 Pressure Control

The emergency system shall control the gas pressure encompassing the crewman's body at a pressure of $8.2 \pm .2$ psia with ambient pressure conditions of space vacuum and with any of one of the flow conditions.

a. Maximum emergency ventilation rate
b. Failed open suit pressure relief valve
c. Excessive system leakage up to 10,000 scc/min

3.1.2.7.3 Contaminant Control

The contaminants of CO_2, particulate and trace contaminants shall be removed from the system by means of an overboard purge. The mean inspired CO_2 partial pressure shall not exceed 15.0 mm of Hg.

3.1.2.7.4 Thermal Control

The crewman's thermal storage shall not exceed 300 Btu's during operation with the emergency life support system.

3.1.2.7.5 Humidity Control

The humidity of the ventilating gas entering the pressure suit from the emergency system shall preclude visor fogging.

3.1.2.7.6 Ventilation

The emergency system shall provide a ventilation gas flow for the removal of contaminants and humidity from the pressure suit. The ventilation flow shall be achieved by purging oxygen from the emergency system, through the suit and purge valve to space vacuum.

3.1.3 Flight Operational Requirements

3.1.3.1 Pre-Egress Check-Out

The EVA system shall be capable of being functionally checked out prior to each EVA to verify proper operation of all systems. The systems shall be capable of check-out as part of systems start-up or airlock operation without reliance on ground personnel. The following functional verifications shall be performed as a minimum:

a. System O_2 pressure integrity verification
b. Primary and emergency oxygen supply subsystems
    1. Quantity
    2. Pressure control under flow conditions
c. Verification of cooling
d. Prime movers operation
e. Communications
f. Performance of critical warnings

3.1.3.2 Controls

All controls required for systems start-up operation and shut-down shall be operable by the unassisted crewman. Controls used for emergency operations shall be readily visible and accessible to the crewman. The operating torques and forces shall be consistent with good human engineering practices and shall be compatible with EVA gloves.

3.1.3.3 Displays

Visual displays shall be incorporated as required for systems check-out, EVA monitoring and warnings. Displays used for EVA monitoring and warnings shall be located within the visual field of the crewman and shall not require the removal of covers or flaps for viewing. Displays used for check-out and EVA monitoring shall be marked with the appropriate engineering units and shall be color coded to distinguish normal and abnormal ranges. Warning displays shall clearly indicate the system malfunction.

3.1.3.4 Warnings

The EVA system shall incorporate a warning system to alert the crewman both visually and audibly of critical system malfunctions. The following warnings shall be incorporated as a minimum:

a. Low suit pressure
b. High CO_2 level
c. Low battery voltage

3.1.3.5 System Performance Monitoring

The system shall be capable of transmitting telemetry data to ground via relay from the spacecraft. The telemetry data shall include a maximum of ten (10) parameters of data for monitoring system performance of critical functions and for establishing equipment maintenance schedules. The telemetry system design shall permit simultaneous non-interfering data transmittal from two EVA crewmen.

3.1.3.6 Donning and Doffing

The system shall allow maximum ease of donning and doffing. For normal mission operations, assistance from other crew members will be available. As a design goal, the system should permit unassisted donning and doffing. The pressure suit should be capable of being donned unassisted and pressurizeable within a three (3) minute period.

3.1.3.7 Recharging

The spacecraft shall provide additional consumables listed below to recharge the life support system as required for performance of subsequent EVA/IVA's.

a. Breathing oxygen
b. Lithium hydroxide
c. Battery recharging
d. Expendable water

The system shall permit concurrent recharging of all consumables in a pressurized environment and shall not require the use of tools.

3.1.4 Operability Requirements

The following paragraphs specify the reliability, maintainability and life requirements of the Shuttle EVA/IVA equipment. These requirements apply from the time of delivery to the procuring agency to the termination of the intended usage unless otherwise specified herein.

3.1.4.1 Reliability

The system design shall be such that no single failure of a component, assembly, subsystem or system shall endanger the life or safety of the crewman during any normal operating mode of the EVA system.

3.1.4.2 Maintainability

Consideration shall be given in the design and construction of the EVA system and its components to the ease of repair and maintenance in the field and during mission use. The design shall be such that the use of special or unusual tools shall be minimized for normal maintenance and checkout of the EMU.

3.1.4.3 Useful Life

The useful life of the EMU and its components is composed of shelf life and operational life requirements. The operational life includes ground test and prelaunch operations. Limited life items are considered in determining the requirements for useful life. The requirements for each aspect of useful life are defined in the following subparagraphs.

3.1.4.3.1 Shelf Life

Shelf life is defined as that period of time that the components of the EVA system can be stored under controlled conditions, during which they may be removed and put into service without replacement of parts. Routine servicing and change out of operational limited life items shall be permissible. The shelf life of hardware (PLSS & ELSS) shall be fifteen (15) years and four (4) years for soft goods (pressure suit, LCG, etc.). The shelf life commences at the time of delivery of the procuring agency and includes periods of earth transportation but does not include time taken for operational usage.

3.1.4.3.1.1 Limited Life Items

Limited life items are defined as being those items which may be replaced during prelaunch operations as a routine part of preventative maintenance and any items which have a lower life limit than the end item. The contractor shall identify all limited life components and specify the frequency of replacement.

3.1.4.3.2 Operational Life

The EVA system shall be utilized over a 15 year period through a comprehensive maintenance and repair program defined by the contractor. As a design goal, the equipment shall comply with the following operational life requirements.

3.1.4.3.2.1 Environmental Control Equipment

Components and subsystems of the Primary and Emergency Life Support Systems shall be designed for operational life of 6000 and 300 hours respectively during the fifteen (15) year period.

3.1.4.3.2.2 Personal Equipment

Personal equipment such as pressure suits and liquid cooling garments shall be designed for an operational life of 300 hours over a four (4) year period. Cyclic life of the pressure suit joints shall be 100,000 cycles per joint.

3.1.4.4 Environments

3.1.4.4.1 Ground Handling and Transportation

The EVA equipment shall be capable of satisfying the performance requirements of this specification after being packaged in a protective container and subjected to the environments specified below:

a. Temperature (Air)

Air Transportation	Minus 20 degrees Fahrenheit (F) to plus 140 F for 8 hours
Ground Transportation	Minus 20°F to plus 145°F for 2 weeks

3.1.4.4.1 Ground Handling and Transportation - Continued

b. Pressure

Air Transportation	Minimum of 3.47 pounds per square inch absolute (psia) for 8 hours (35,000 feet (ft.) altitude)
Ground Transportation	Minimum of 11.78 psia for 3 years (6,000 ft. altitude)

c. Humidity	Zero to 100 percent relative humidity including conditions wherein condensation takes place in the form of water or frost for up to 24 hours
d. Sunshine	Solar radiation at 360 British thermal units (Btu)/square foot (ft^2)/hour for 6 hours per day for 24 hours
e. Rain	Up to 0.6 inch/hour for 12 hours or 2.5 inches/hour for one hour
f. Sand and Dust	Equivalent to 140 mesh silica flour with particle velocity up to 400 feet per minute and a particle density of 0.25 gram/cubic feet (ft^3)
g. Fungus	Materials will not be used which will support or be damaged by fungi
h. Salt Spray	Salt atmosphere as simulated by exposure to a 5 percent salt solution by weight for 48 hours
i. Ozone	Three years exposure, including 72 hours at 0.5 part per million (ppm), 3 months at 0.25 ppm, and the remainder at 0.05 ppm concentration.

j. Shock

The unit shall be capable of surviving the following bench handling shocks when dropped on a horizontal, solid wooden bench top at least 1 5/8 inches thick.

3.1.4.4.1 Ground Handling and Transportation - Continued

1. Using one edge as a pivot, tilt the opposite edge of the unit until the horizontal axis forms an angle of 45 degrees with the table, or the opposite edge is 4 inches above the table, whichever occurs first, and permit the unit to drop freely to the horizontal. Repeat, using other practicable edges of the same horizontal face as pivots, for a total of four drops.

2. Repeat (a), with the unit resting on other faces until it has been dropped for a total of four times on each face on which the unit could be placed practicable during servicing.

3.1.4.4.2 Ground Storage

The EVA equipment shall satisfy the performance requirements of this specification after ground storage in a Class 100,000 clean room per FED-STD-209.

3.1.4.4.3 Spacecraft Induced Environments

The EVA equipment shall satisfy the requirements of this specification after being subjected to the spacecraft induced environments specified below:

a. Temperature	From 35 to 90°F
b. Pressure	1×10^{-4} millimeters of mercury (mm Hg) to 15.0 psia air
c. Acceleration	20 g's ultimate acceleration in each direction along each of three orthogonal axes
d. Salt Atmosphere	Salt atmosphere as simulated by exposure to a one-percent salt solution by weight for one hour
e. Humidity	Zero to 100 percent relative humidity for 30 days including conditions where condensation takes place in the form of water or frost

3.1.4.4.3 Spacecraft Induced Environments - Continued

f. Vibration — Random vibration in accordance with Figure 7

g. Shock

1. Landing - Rectangular pulses of the following peak accelerations, time durations and number of applications in the minus Z direction of the spacecraft.

Acceleration	Duration	Application
.23 g peak	170 M sec	32
.28	280	37
.35	330	32
.43	360	20
.56	350	9
.72	320	4
1.50	260	1

2. Crash safety for spacecraft crew and passenger compartment locations - terminal peak sawtooth pulse of 10 to 15 M sec duration in the X, Y and Z axes as follows:

Pulse X = 0, minus X = 20g
Pulse Y = 6.8 g, minus Y = 6.8 g
Pulse Z = 0, minus Z = 10 g

3.2 Interface Requirements

3.2.1 General

The EVA system shall interface with the Space Shuttle Orbiter spacecraft for accomplishment of EVA tasks associated with each flight. The Orbiter provides supporting subsystems and facilities defined herein as required for the following:

a. Thirty-two (32) man-hours of systems expendables.

b. A maximum of six (6) airlock depressurizations/repressurizations.

c. EVA equipment stowage, servicing and supporting subsystems.

3.2.2 EVA Equipment Servicing

3.2.2.1 Oxygen Recharging

The PLSS oxygen supply subsystem shall be rechargeable from the Orbiter oxygen recharge system having the following performance capabilities:

a. Oxygen - per MIL-0-27210
b. Pressure - 900 I $\pm$ 20 psia
c. Temperature - 90°F maximum

The atmospheric conditions during recharge are:

Temperature - 90°F maximum
Pressure - 14.7 psia

3.2.2.2 Water Recharge

The PLSS expendable water supply subsystem shall be rechargeable from the Orbiter water charging subsystem having the following performance capabilities:

a. Pressure - 20 to 38 psia
b. Temperature - 90°F maximum
c. Water purity - PF-SPEC-1
d. Bacteracidial agent - PPM silver ions
e. Dissolves gases - Nitrogen saturated at 38 psia

3.2.2.3 Power Supply Recharge

After a four (4) hour EVA, the PLSS power supply shall be rechargeable within sixteen (16) hours from the Orbiter battery charging subsystem having the following performance capabilities:

Current - Constant within the range of 1.4 to 2.0 amps.

Cut-off Voltage - Within the range of 18 to 24 VDC

3.2.2.4 Umbilical Cooling

The EVA system shall satisfy the performance requirements of this specification while operating with coolant supplied to the EVA system in accordance with the following:

a. Coolant - water
b. Flow rate - 240 lbs/hr minimum
c. Inlet temperature - 55°F maximum
d. Pressure differential - 5.0 psi minimum

3.2.3 EVA Support Equipment Stowage

The EVA equipment shall be capable of being stowed on board the Orbiter for the durations specified in Table II.

3.3 Design and Construction

3.3.1 General Design Requirements

3.3.1.1 Weight

The weight of the EVA system shall not exceed the following:

a.	Pressure Suit	53.0 pounds
b.	Liquid Cooling Garment	5.0
c.	Urine Collection Assembly	1.0
d.	Comm. Headset and Microphones	2.0
e.	EV Visors	6.0
f.	Primary Life Support System Basic System	79.0
g.	Emergency Life Support System	25.0
h.	Integrated PLSS/ELSS	96.0
i.	Purge Valve	1.0

Totals

Separate PLSS & ELSS	=	172.0 lbs. maximum
Integrated PLSS/ELSS	=	164.0 lbs. maximum

3.3.1.2 Configuration

The configuration of the EVA system shall afford the crewman with maximum ease of translation and task performance. The location of equipment on the crewman's frontal area which could interfere with crewman's task performance should be avoided.

3.3.1.2.1 Pressure Suit Sizing

The pressure suit sizing is to accommodate crewmen of the 5th to 95th percentile. Custom tailoring to each individual crewman is to be avoided. Consideration shall be given to the fabrication of standard sizes with the incorporation of adjustment capabilities as required to accommodate all crewmen.

3.3.1.3 Center of Gravity

The mass distribution of the EVA system shall be such that the center of gravity of the combined mass of a standing crewman wearing the EVA system will be located within seven (7) inches vertically and three (3) inches horizontally of the center of gravity locations for the nude standing crewman.

3.3.1.4 Structural Requirements

3.3.1.4.1 Proof Pressure

The EVA system shall be capable of satisfying the requirements of this specification after being subjected to a proof pressure of 1.5 times the maximum operating pressure of the system or subsystems. For those subsystems incorporating pressure relief provisions the proof pressure factor of 1.5 shall be applied to the nominal operating pressure of the relief provision.

3.3.1.4.2 Burst Pressure

The EVA system and its subsystems shall not rupture but may permanently deform when subjected to a burst pressure of 2.0 times the maximum operating pressure of the system or subsystem. For those subsystems incorporating pressure relief provisions, the burst pressure factor of 2.0 shall be applied to the nominal operating pressure of the relief provision.

3.3.1.5 Mechanical Locks

All adjustments for calibrations shall be mechanically locked to prevent change in component performance. A redundant interlocking feature shall be incorporated on interfacing connectors to prevent accidental release during EVA.

3.3.1.6 Electrical Systems Design

Detail electrical design requirement shall be in accordance with MSC-A-D-66-7.

3.3.1.6.1 Electrical System Configuration

The EVA system electrical system configuration shall comply with MSC/IESD 19-3. The system shall incorporate a negative ground system consistent with the electromagnetic interference (EMI) requirements specified in MSC/IESD 19-3.

3.3.1.6.2 Electrical and Electronic Systems

Electrical and electronic systems shall be in accordance with the following general requirements:

a. Motors using mechanical commutation or slip rings shall not be used.

b. All switches shall be hermetically sealed.

c. The system shall incorporate current limiting devices in the circuits for all power consuming devices, except prime mover circuits.

d. Insulation resistance of all terminal boxes and electrical harnesses shall be a minimum of 50 megohms at room ambient dry conditions and a minimum of one (1) megohm after environmental exposure (humidity and salt fog) with an impressed voltage of 100 volts DC in accordance with MIL-STD-202, Method 302, test condition A.

3.3.1.6.3 Electromagnetic Interference

The EVA system shall comply with the EMI requirements of MSC/IESD 19-3.

3.3.1.6.4 Electrical Wiring

Electrical wiring shall be routed and supported to:

a. Prevent chafing and provide protection from sharp edges and hot spots.

b. Provide bend radii greater than ten (10) times the outside diameter of the wiring.

c. Prevent mechanical strain that would tend to break conductors and/or connections.

d. Prevent excessive movement under all vibration conditions.

3.3.2 Selection of Specifications and Standards

In order to achieve the highest degree of standaridzation and productivity off-the-shelf components and standard parts shall be utilized wherever practicable.

3.3.3 Materials, Parts and Processes

Materials, parts and processes shall conform with applicable specifications and shall be of high quality suitable for the purpose. Organic and inorganic materials used in the fabrication of the EVA system shall be compatible with mission requirements and be of consistent chemical composition. The materials used shall not produce detrimental interactions injurious to the crewman or the materials and/or the systems of the spacecraft.

3.3.3.1 Materials Degradation

Selected materials shall not, as a result of exposure to the environments defined in Sections 3.1.4.4, evolve degradation products that are chemically reactive or are of such concentration as to impair or degrade the performance of the crewman, the spacecraft or the EVA system. Materials shall meet the out-gassing and odor requirements of NASA Document MSC-PA-D-67-13.

3.3.3.2 Thermal Transients

Any thermal transient which occurs as a result of performing the intended mission (including contingencies and/or short term emergencies), shall not degrade the performance of any materials used.

3.3.3.3 Dissimilar Materials

Materials used in the fabrication of the EVA system shall not react, combine, or fuse with each other or with the spacecraft materials when placed in physical contact during the mission.

3.3.3.4 Combustion and Flammability

Materials exposed to oxygen service shall be selected in accordance with the criteria established in MSC-PA-D-67-13.

3.3.3.5 Welding and Brazing

Welding and brazing methods shall meet the requirements of MIL-W-22248 or equivalent specifications as approved by NASA.

3.3.3.6 Castings and Stressed Areas

Stress concentration shall be avoided or minimized. Castings shall be classified stress-wise and radiographically in accordance with MIL-C-6021. Castings shall be of high grade, clean, sound and free from blow holes, porosity, cracks and other defects. Degree and method of inspection shall be approved by NASA.

3.3.3.7 Lubricants and Lubrication

All lubricants shall be compatible with the intended environments defined in this specification and meet the applicable requirements of MSC-PA-D-67-13.

3.3.3.8 Age Control

Age control of rubber parts shall be in accordance with ANA Bulletin 438.

3.3.3.9 Moisture and Fungus Resistance

Materials used in the EVA system shall not support bacteriological and fungus growth during the useful life of the system.

3.3.3.10 Finish Protection and Corrosion Prevention

All materials used in the EVA system shall be treated to resist corrosion if not inherently corrosion-resistant, or unless the finished product will be located in a manner that it will be protected by non-corrosive lubricating film.

No finishes, paints, or color markings other than those specified shall be applied to the system components, either externally or internally. All surface coatings or mating surfaces should be electrically conductive, if practicable, to prevent static charge accumulation.

Dissimilar metals shall not be used in intimate contact with each other unless protected against electrolytic corrosion. Dissimilar metals are defined in MS 33586.

3.3.3.10 Finish Protection and Corrosion Prevention - Continued

Surface roughness shall be defined on drawings in accordance with USAS B46.1-62.

Surface protection shall be in accordance with MSFC-STD-181.

Use of alodyne shall be in accordance with MIL-A-5541, and use of anodize shall be in accordance with MIL-A-8625.

3.3.4 Standard and Commercial Parts

Standard parts (MS, AN, NAS, and commercial) shall be used wherever they are suitable for the purpose. As a guide for selection of standard parts, the various indexes or government documents listed in MIL-STD-143 is recommended for review. Selection of electrical and electronic parts shall be in accordance with MSC-A-D-66-7.

3.3.5 Interchangeability and Replaceability

3.3.5.1 General

All replaceable parts or assemblies having the same part number shall be directly and completely interchangeable with each other with respect to installation and performance. Each assembly shall be designed to be replaceable with all other assemblies having the same part number without requiring the replacement of the other assemblies.

Changes in part numbers shall be governed by ANA Bulletin 445 as modified by MSC Supplement No. 1, Revision B, Appendix B, and NASA direction. The requirements of MIL-D-1000 and MIL-STD-100 will govern methods and practices of drawing number changes.

Interchangeability requirements are not applicable to detail parts of permanent assemblies such as welded assemblies, or matched detailed parts such as lapped components. Interchangeability requirements do not apply to custom fitted or sized items.

3.3.6 Installation and Maintenance

The EVA system shall be designed to facilitate maintenance and replacement. The design shall be such that special or unusual tools will not be required for normal maintenance and inspection of the unit. Minimum manual dexterity shall be required for maintenance operations.

3.3.7 Workmanship

Workmanship shall be of aerospace quality, consistent with the reliability requirements of the type of equipment, and shall conform to high grade aerospace manufacturing practices. All external edges and corners of parts shall be rounded or smooth to prevent injury to personnel handling and equipment.

3.3.8 Identification and Marking

3.3.8.1 Identification

Each unit shall be provided with a nameplate clearly and permanently marked with letters not less than .060 inches high. The nameplate shall meet the requirements of specification MIL-P-6906 except that the 125°C specified in the high temperature test shall be replaced by 130°F.

The nameplate shall be securely attached by use of screws, rivets, welding or other approved methods. The nameplate shall be attached to a surface exposed if possible, after installation, and shall not be attached to a mounting face. Decalcomanias of any material shall not be used.

3.3.8.2 Marking

In general, the marking of items shall be accomplished by suitable methods and materials which will not adversely affect the life, or utility of the components to which they are applied. All markings shall be capable of withstanding the environmental and life expectancy requirements of the component to which they are attached and shall be permanent and legible as required for ready readability.

All safety precautions shall be clearly marked on a prominent component location with contrasting print.

The equipment shall be permanently marked to indicate instrumentation, fluid and electrical connections.

The equipment shall be permanently marked with an arrow indicating direction of flow.

4.0 QUALITY ASSURANCE PROVISIONS

The EVA system shall be designed and constructed under a quality assurance program in accordance with NHB 5300.4 and a reliability program in accordance with NPC-250-1. Any contractor implementation plans must have the express approval of NASA.

4.1 Developmental Test Requirements

Developmental tests shall be performed to assure the proper functioning of the components of the EVA system. Specific developmental test objectives shall be:

a. Determination of the feasibility of design approach.

b. Evaluation of end item performance under simulated operational environmental conditions.

c. Evaluation of end item failure modes and safety factors.

The developmental tests shall be performed using developmental hardware which is representative of (but not necessarily identical to) the flight end items and the operational GSE. The detailed test requirements and the identification of the specific developmental tests required shall be given in the Developmental Test Program Plan which shall be prepared in accordance with NASA Quality Publication NHB 5300.4.

4.2 Acceptance Test Requirements

4.2.1 Pre-Delivery Acceptance Tests

4.2.1.1 Scope

Acceptance tests shall be conducted on all parts, components and assemblies of the EVA system to determine conformance to design specifications as a basis for acceptance. Acceptance tests shall include receiving tests on parts and materials, in-process tests performed at intermediate points during production and final pre-delivery acceptance tests of the final assembly. All acceptance tests shall be performed at the manufacturer's plant. The detailed test requirements shall be given in the Acceptance Test Program Plan to be prepared in accordance with NASA Quality Publication NHB 5300.4 and are summarized in the following subparagraphs.

4.2.1.2 Test Program

The pre-delivery acceptance test program shall consist of the following tests:

a. Drawing compliance and examination of product
b. Vibration
c. Thermal cycling
d. Proof pressure
e. Leakage
f. Performance
g. Weight
h. Examination of product

4.2.1.3 Test Description

4.2.1.3.1 Drawing Compliance and Examination of Product

This examination shall consist of first reviewing all applicable engineering change records and component build-up and test records to assure that the assembled system has been built to the correct configuration using all required hardware and in accordance with established assembly procedures. The system shall then be visually inspected in depth for any discrepant conditions not in compliance with the drawings or standard manufacturing processes.

4.2.1.3.2 Vibration

The vibration test shall verify the structural integrity of the assembly and the integrity of all electrical connections.

4.2.1.3.3 Thermal Cycling

The thermal cycling test shall verify electrical continuity and the operation of electrical motors at high and low temperature soaks.

4.2.1.3.4 Proof Pressure

This test shall verify the structural integrity of the pneumatic and hydraulic subsystems of the assembly. The test should be conducted at a level of 1.5 times the normal operating pressure of each subsystem.

4.2.1.3.5 Leakage

Leakage tests are performed at the normal operating pressure of each subsystem to verify the integrity of all seals and closures.

4.2.1.3.6 Performance Tests

The performance test shall serve the multiple function of verifying equipment capability, establishing baselines for future performance evaluations and burn-in of electrical and rotating equipment. During this test every component in every subsystem shall be tested in all modes of operation.

4.2.1.3.7 Weight

This test shall be performed to verify that the assembled system satisfies the specification's maximum weight requirement.

4.2.1.3.8 Examination of Product

This visual examination shall be conducted to assure that no damage has occurred to the system during the test program and to verify that the system is ready for delivery.

4.2.2 Pre-Flight Acceptance Test

4.2.2.1 Scope

Acceptance tests shall be conducted on all components and assemblies of the EVA system to determine conformance to design specifications as a basis for acceptance for flight usage. Acceptance tests shall be as summarized in the following subparagraphs and shall be performed at the launch facility. The detailed test requirements shall be given in the Pre-Flight Acceptance Test Program Plan to be prepared in accordance with NASA Quality Publication NHB 5300.4.

4.2.2.2 Test Program

The pre-flight acceptance test program shall consist of the following tests:

a. Examination of product
b. Deactivation
c. Leakage
d. Functional

4.2.2.3 Test Description

4.2.2.3.1 Examination of Product

Immediately upon return from a flight, the EVA system shall be subjected to a detailed visual examination for evidence of any damage, or other degradation. In addition, all telemetered data from the flight shall be reviewed for any evidence of incipient change in system performance or integrity.

4.2.2.3.2 Deactivation

This process shall be performed to assure that the system does not have residual pressure in it at the time of starting the pre-flight acceptance test and to assure that the system cleanliness level is maintained by the periodic removal of all fluids.

4.2.2.3.3 Leakage Tests

The leakage checks shall serve as the primary means of assuring the pressure integrity of the system during pre-flight testing.

4.2.2.3.4 Functional Tests

The functional checks on the system components shall be conducted to provide assurance that the system is capable of use on the next flight. All tests shall be single point checks in each normal mode of operation.

4.3 Qualification Requirements

4.3.1 General

A formal design qualification program shall be conducted to demonstrate that the EVA system is adequate to meet the requirements of this specification.

The EVA system shall be qualified at the total system level for electro-magnetic compatibility, vehicle/mission functional interface compatibility and system performance verification. All other aspects of certification of the EVA system equipment shall be accomplished at the equipment end item/assembly level and shall be performed by the manufacturer(s) in accordance with test plans and procedures approved by NASA.

4.3.2 Qualification Methods

Several methods of qualifications are available to supplier of EVA system equipment. These methods are qualification by test, demonstration, similarity, analysis, and waiver. The definitions and prerequisites for qualification by each of these approved methods are included in document ASPO-RQA-11 "Certification Test Program Guidelines" and are summarized in the following paragraphs. All EVA system equipment shall be qualified for each Shuttle mission as attested to on a Certification Test Review (CTR) sheet before use on any spacecraft. It is the responsibility of the organization that provides the flight hardware to generate and obtain approval of CTR sheets for each item of equipment. Satisfaction of the criteria for the qualification shown is the basis for acceptance of CTR sheets.

4.3.2.1 Qualification by Test

Qualification by test is defined as "a controlled demonstration of the ability of one set of equipment to function properly during and after exposure to design proof tests in sequential, single applied environments at design limit conditions and another set of equipment to be subjected to mission cycle at nominal mission conditions." This method is the primary bais for qualification certification. Qualification by test involves the conduct of formal qualification demonstrations meeting rigorous control, quality inspections and detailed documentation standards.

4.3.2.2 Qualification by Demonstration

Qualification by demonstration may be used us a certification method, providing the following criteria are applied.

a. Certification demonstrations shall be planned as a logical extension of the qualification test program, so that when the data from these tests are integrated with qualification test data, all normal modes of operation shall have been demonstrated.

b. Redundant or alternate modes of operation shall be tested to demonstrate complete integrated performance and interface compatibility.

c. Emphasis shall be placed on mission simulation and interaction effects.

4.3.2.2 Qualification by Demonstration - Continued

d. Production hardware shall be used unless it can be shown by analysis that the specific test objectives will not be compromised by the use of nonproduction hardware. Refurbished equipment may be used if it passes an acceptance test after refurbishment.

4.3.2.3 Qualification by Similarity

Qualification by similarity to equipment from other programs and to equipment from within the Shuttle program may be accepted if all of the following conditions have been met.

a. The similar item was qualified to the manned-orbital mission environment levels.

b. The qualification item was fabricated by the same manufacturer with exactly the same processes and quality control as the previously qualified item.

c. The qualification item was designed to equivalent specifications required of the Shuttle design.

4.3.2.4 Qualification by Analysis

In situations where complete certification of flight hardware can not be achieved by ground testing, appropriate analyses must be conducted. The analyses must complement testing so that the two provide complete fulfillment of the objectives of qualification. The certification analysis normally will be required because of one or more of the following factors.

a. Inability to simulate flight conditions in an effective ground test.

b. The requirement to compensate for test-program deficiencies that result from schedule or economic limitations.

c. The need to extrapolate test data beyond the performed test points to provide demonstration of design conditions.

4.3.2.5 Qualification Waivers

In some situations, it may be appropriate to approve qualification by waiver in accordance with ASPO-RQTD-D67-1 when doubt exists as to the validity of requirements. An approval with waiver implies that the contractor must provide some further evidence or demonstration to achieve complete approval.

4.3.2.5.1 Approval

The basis for approvals with waiver are as follows:

a. Testing of an item fulfills certification test requirements, but the certification test requirements do not reflect the design specification requirements.

b. Testing of an item fulfills the CTR and test-plan requirements and the design-specification requirements, but the requirements are inadequate for the mission.

c. Failures have occurred that are related to, but not a part of, qualification testing. Satisfactory resolution of the failures are required for approval.

d. Testing was conducted on production hardware of a different configuration from the flight hardware, and a reasonable doubt exists as to the validity of the similarity. The supplier shall be required to demonstrate a sufficient degree of similarity.

e. Analysis or development testing demonstrates that an environmental level is reduced by means of protective measures to an acceptable level.

f. The insensitivity of an item to a particular environment can be positively established.

4.3.2.5.2 Disapproval

Disapproval of qualification by waiver must be given when the following conditions exist.

a. Clear evidence exists that the CTR or test plan has not been fulfilled.

b. An unresolved failure occurred during qualification testing.

c. The test methods, equipment, or conduct was such as to invalidate the test results.

d. The supplier failed to provide sufficient evidence to justify approval of qualification.

e. Qualification testing was conducted on prototype or refurbished hardware without prior Reliability and Quality Assurance office (R&QA) approval.

4.4 Reliability and Quality Assurance

All R&QA activities, including the generation, processing and disposition of any DR, MRR, TPS, and failure reports shall be in strict accordance with MSCM-5312, part 4 "Records and Reports".

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TABLE I

TRACE GAS CONTAMINATION MODEL

CONTAMINANT	BIOLOGICAL PRODUCTION RATE, LB/HR	ALLOWABLE CONCENTRATION, MG/M^3
ACETALDEHYDE	9.6×10^{-9}	360
ACETONE	2.02×10^{-8}	2400
AMMONIA	2.62×10^{-5}	70
n-BUTANOL	1.2×10^{-7}	303
BUTYRIC ACID	6.92×10^{-5}	144
CARBON MONOXIDE	1.43×10^{-6}	115
ETHANOL	3.68×10^{-7}	1880
HYDROGEN	8.08×10^{-7}	(4.1%)
HYDROGEN SUFFIDE	4.61×10^{-10}	28
INDOLE	9.18×10^{-6}	126
METHANE	1.3×10^{-5}	(5.3%)
METHANOL	1.39×10^{-7}	262
PHENOL	3.46×10^{-5}	19
PYRUVIC ACID	1.92×10^{-5}	9.2

TABLE II

EVA EQUIPMENT STOWAGE REQUIREMENTS

MISSION PHASE	DURATION
PRELAUNCH	2 DAYS
LAUNCH AND BOOST	90 MINUTES
EARTH ORBIT	7 DAYS NOMINAL 30 DAYS MAXIMUM
RE-ENTRY AND LANDING	100 MINUTES

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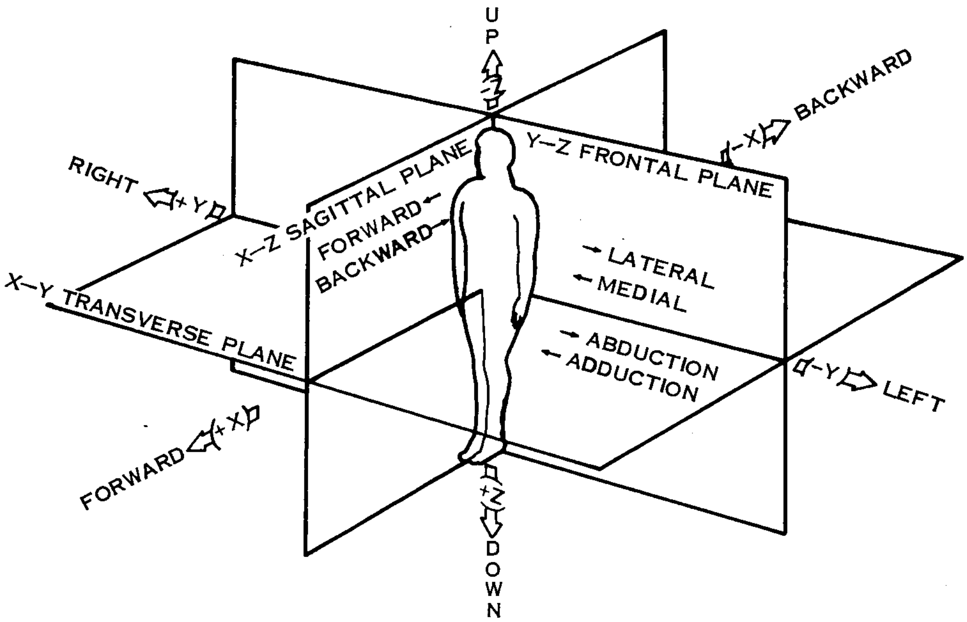

DEFINITIONS

ABDUCTION	AWAY FROM X–Z PLANE IN X–Y PLANE
ADDUCTION	TOWARD X–Z PLANE IN X–Y PLANE
EXTENSION	STRAIGHTENING OR INCREASING ANGLE BETWEEN BODY PARTS
FLEXION	BENDING OR DECREASING ANGLE BETWEEN BODY PARTS
LATERAL	AWAY FROM X–Z PLANE IN Y–Z PLANE
MEDIAL	TOWARD X–Z PLANE IN Y–Z PLANE
PRONATION	FACE DOWN
SUPINATION	FACE UP OR ON BACK
ROTATION	REVOLVING ABOUT THE AXIS OF A BODY PART

FIGURE 1 MOBILITY REQUIREMENTS

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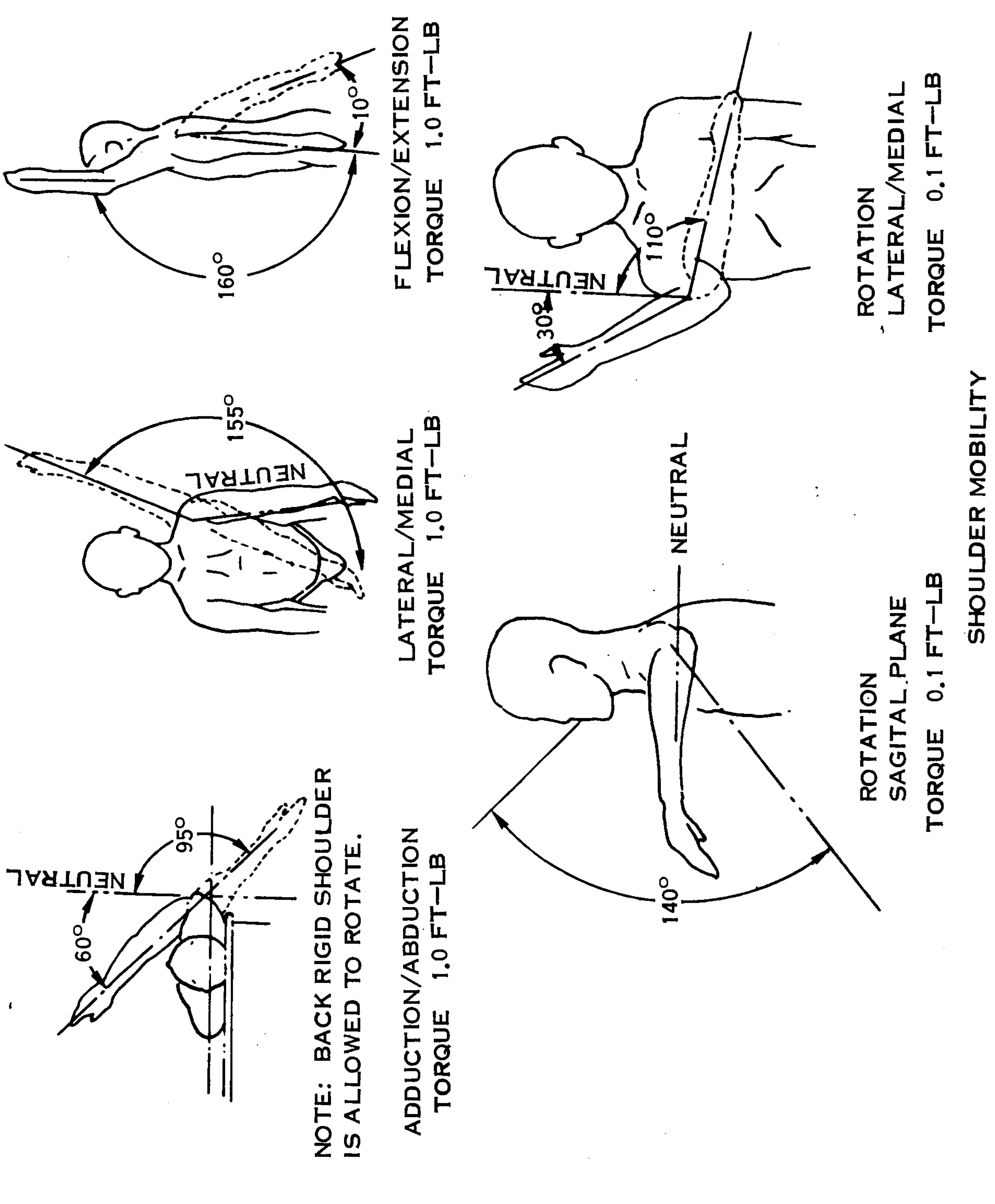
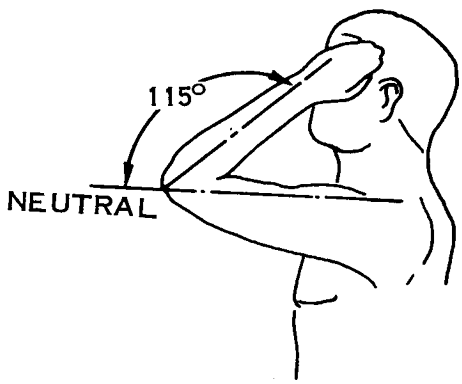
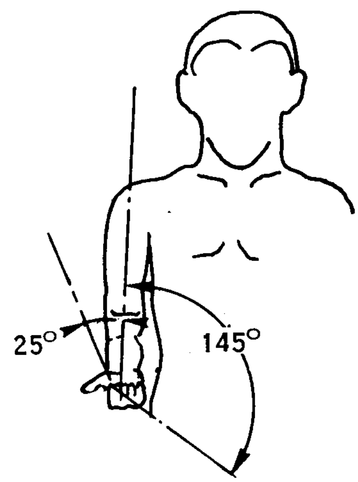


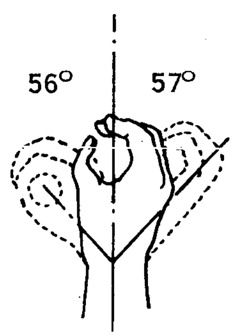
FIGURE 1 CONTINUED



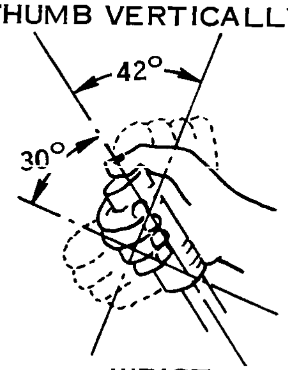
ELBOW
FLEXION–EXTENSION
TORQUE 1.0 FT–LB



FOREARM SUPINATION (PALMS UP)
AND PRONATION (PALMS DOWN)
NOTE: NEUTRAL IS PALM
PERPENDICULAR TO FLOOR
WITH THUMB VERTICALLY UP



WRIST ADDUCTION/
ABDUCTION
TORQUE 0.1 FT–LB



WRIST
FLEXON/EXTENSION
(FORWARD/BACKWARD)
TORQUE 0.1 FT–LB

ARM JOINT MOBILITY

FIGURE 1 CONTINUED

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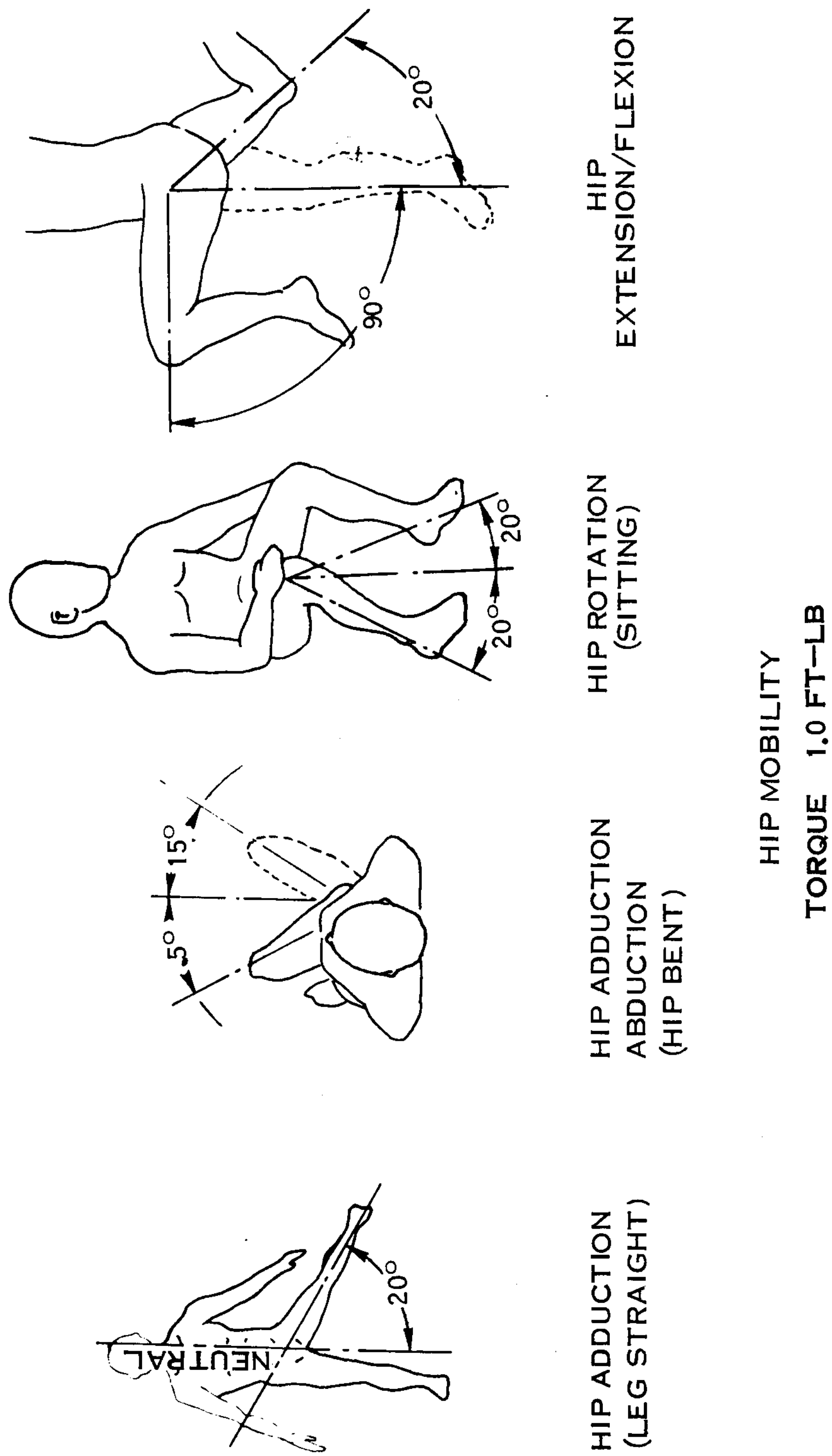

FIGURE 1 CONTINUED

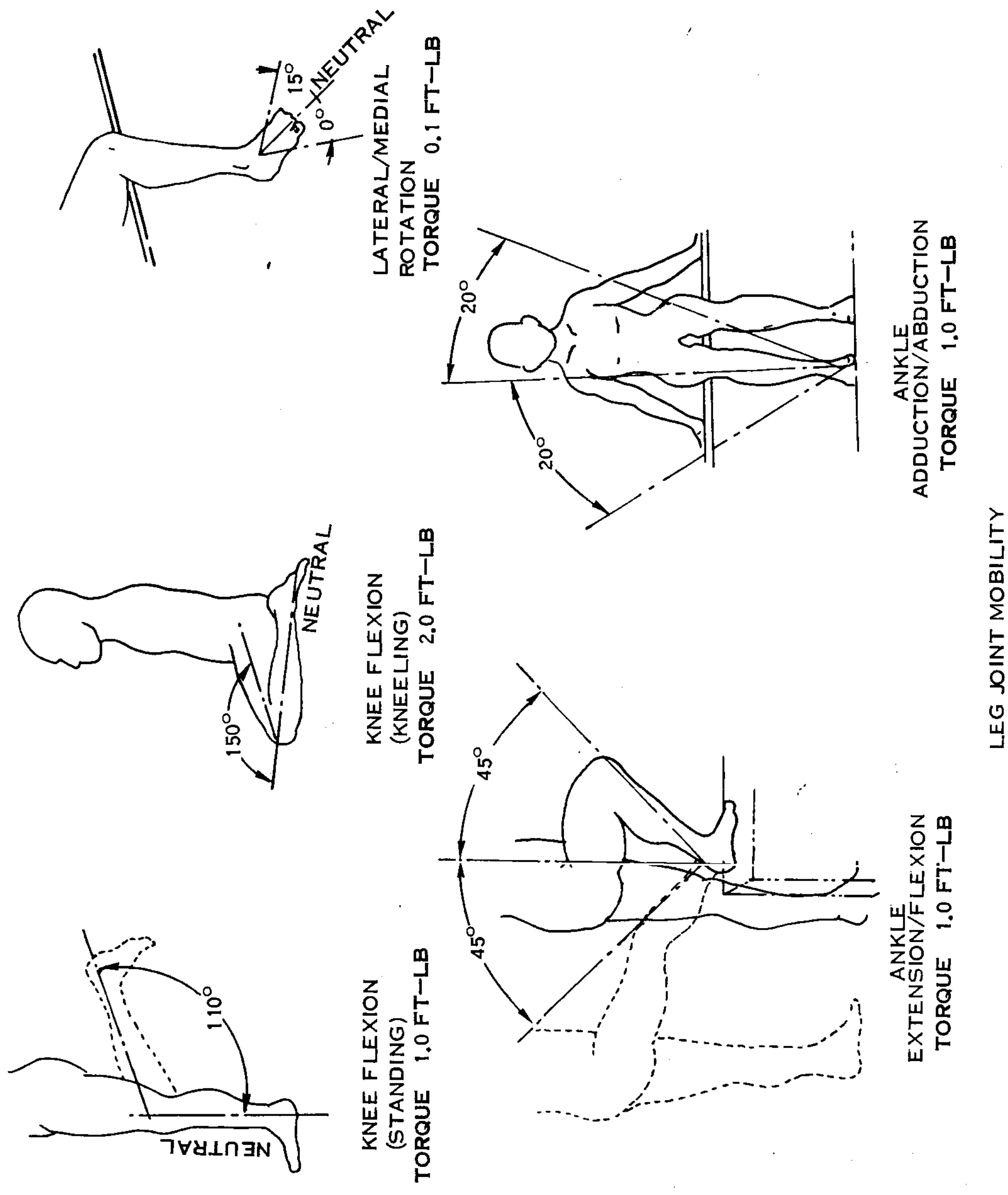

FIGURE 1 CONTINUED

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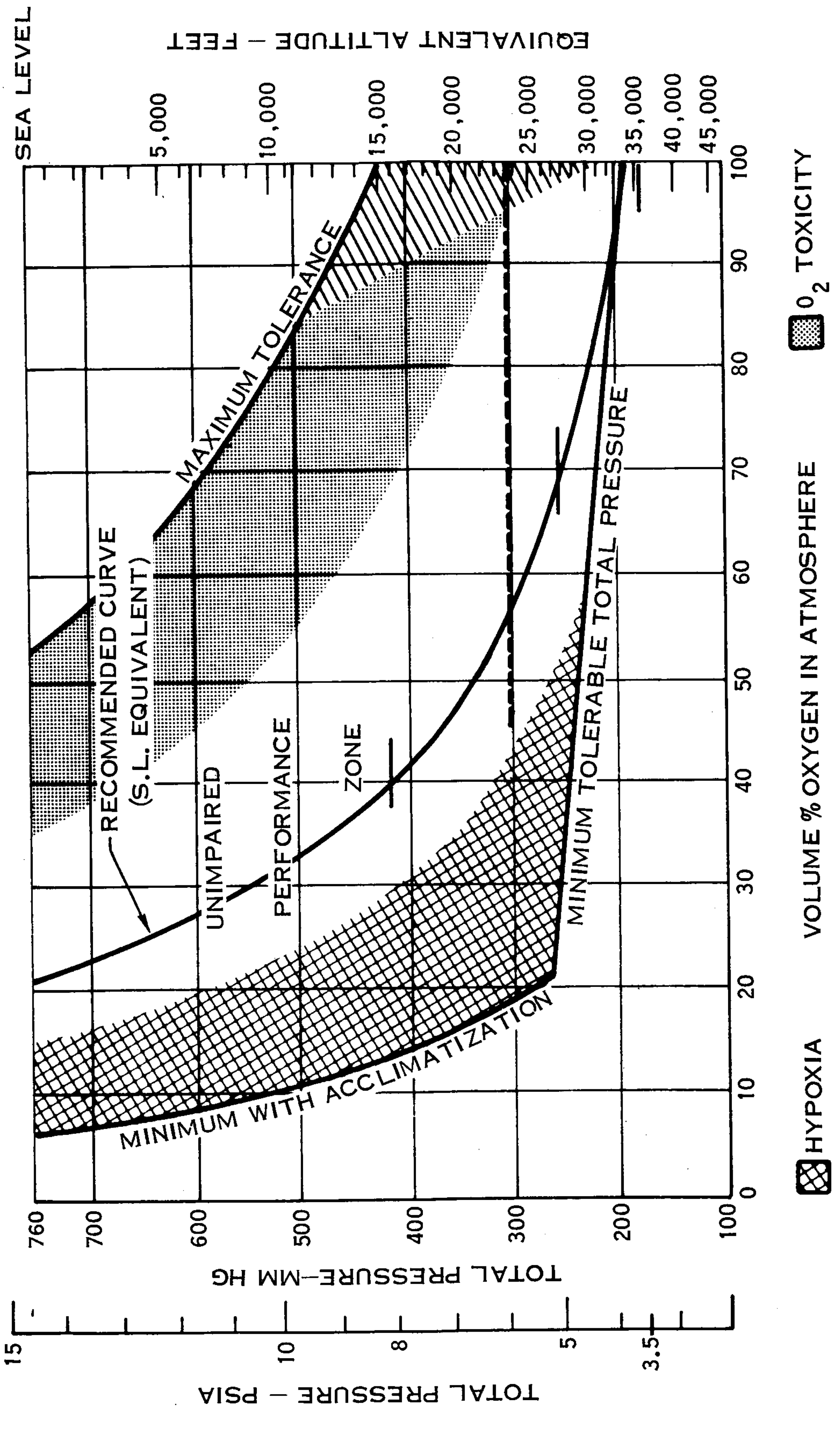

FIGURE 2 REQUIRED OXYGEN CONCENTRATIONS

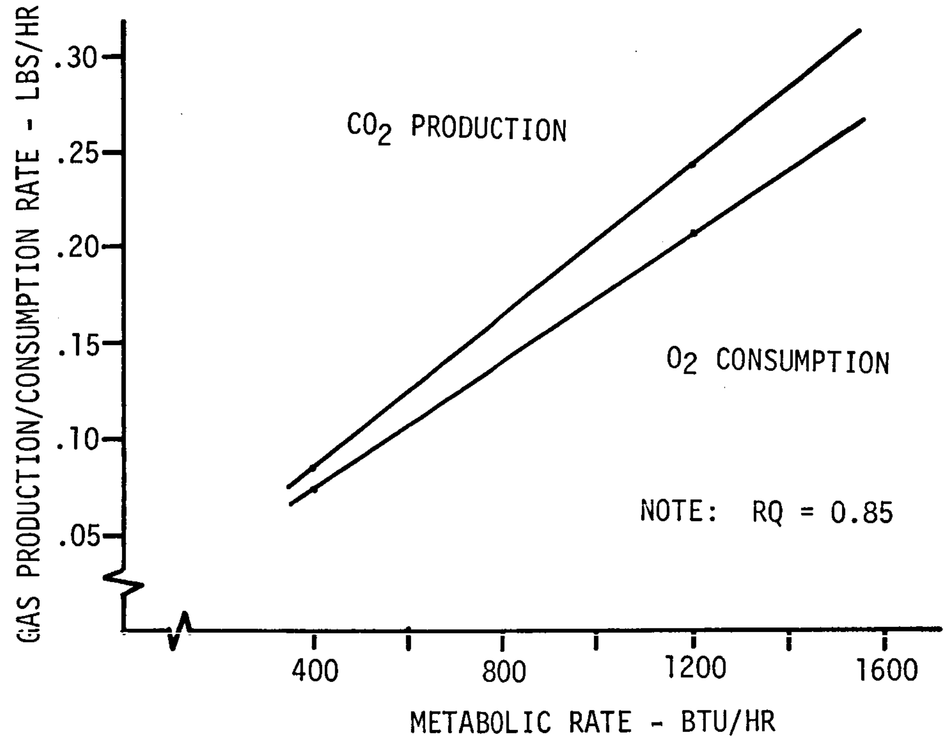

FIGURE 3 O_2 CONSUMPTION/CO_2 PRODUCTION

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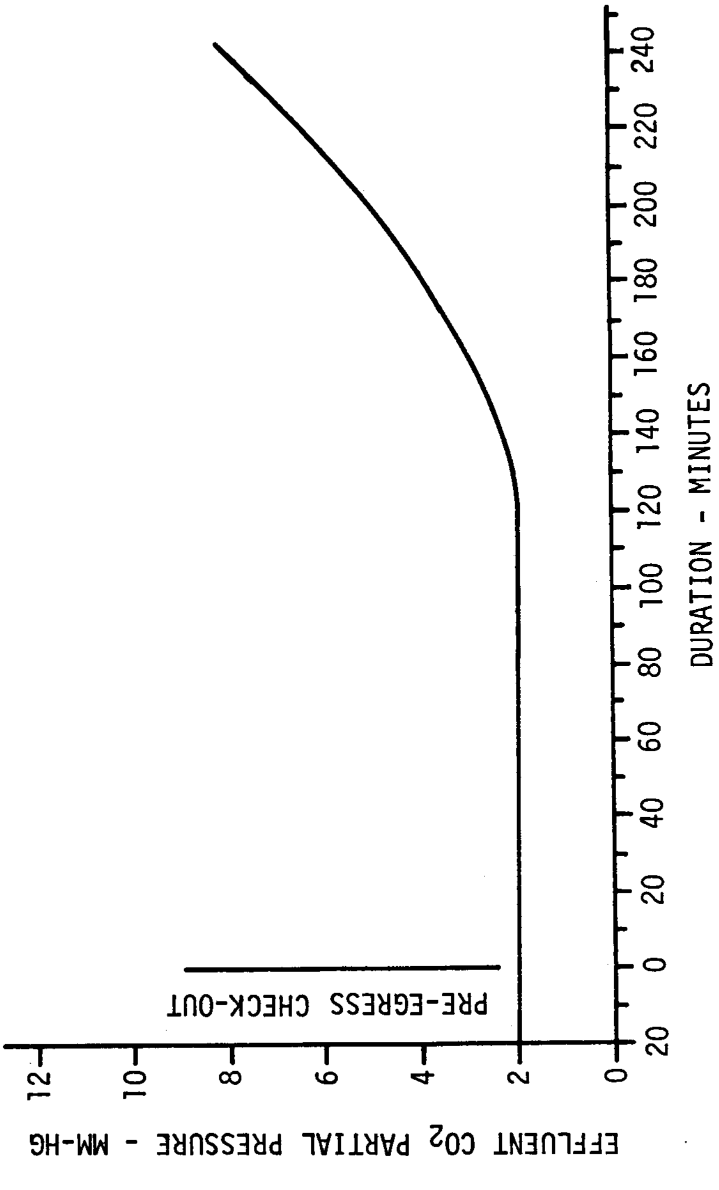

FIGURE 4 LiOH CO_2 PERFORMANCE REQUIREMENTS

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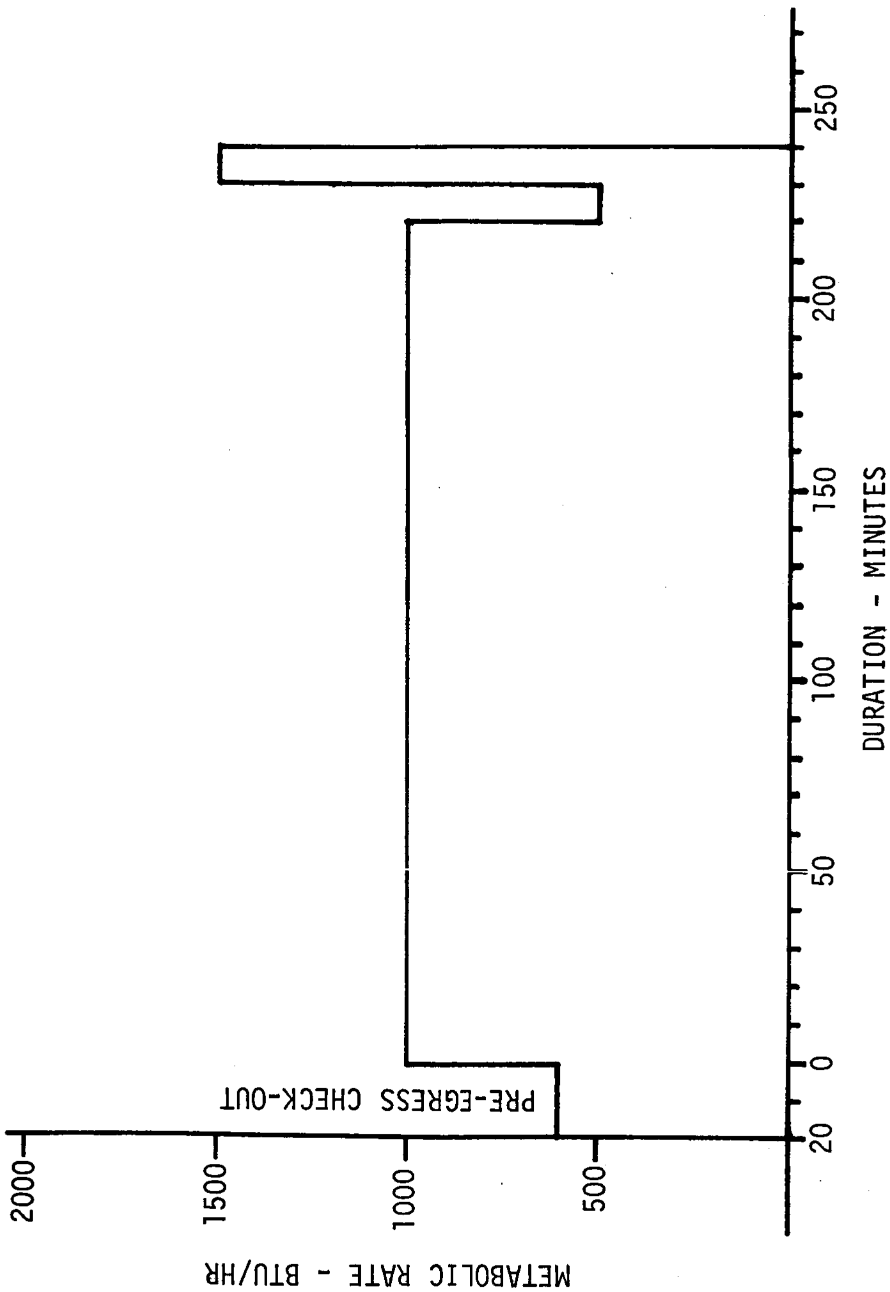
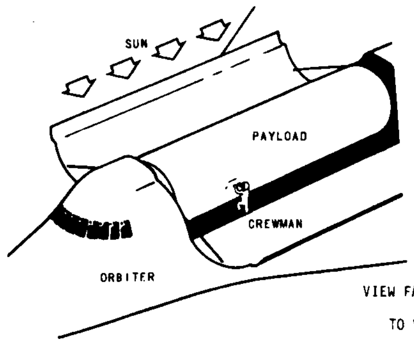


FIGURE 5 METABOLIC PROFILE



VIEW FACTORS

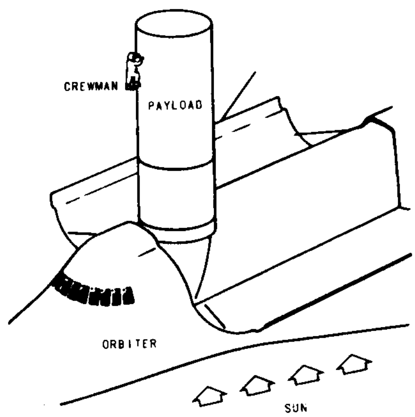
TO VEHICLE SURFACES 80%
TO SPACE 20%

VEHICLE AND PAYLOAD SURFACE PROPERTIES

SOLAR ABSORBTIVITY 0.2
INFRARED EMISSIVITY 0.8
SURFACE TEMPERATURE + 200F

THERMAL MODEL - HOT CASE

CREWMAN LOCATIONS
IN SHADOW OF ORBITER WITH NO VIEW FACTOR
TO EARTH OR ORBITER RADIATORS



VIEW FACTORS

TO DEEP SPACE 80%
TO VEHICLE AND PAYLOAD SURFACES 20%

VEHICLE AND PAYLOAD SURFACE PROPERTIES

SOLAR ABSORBTIVITY = 0.2
INFRARED EMISSIVITY = 0.8
SURFACE TEMPERATURE -250F

THERMAL MODEL - COLD CASE

FIGURE 6

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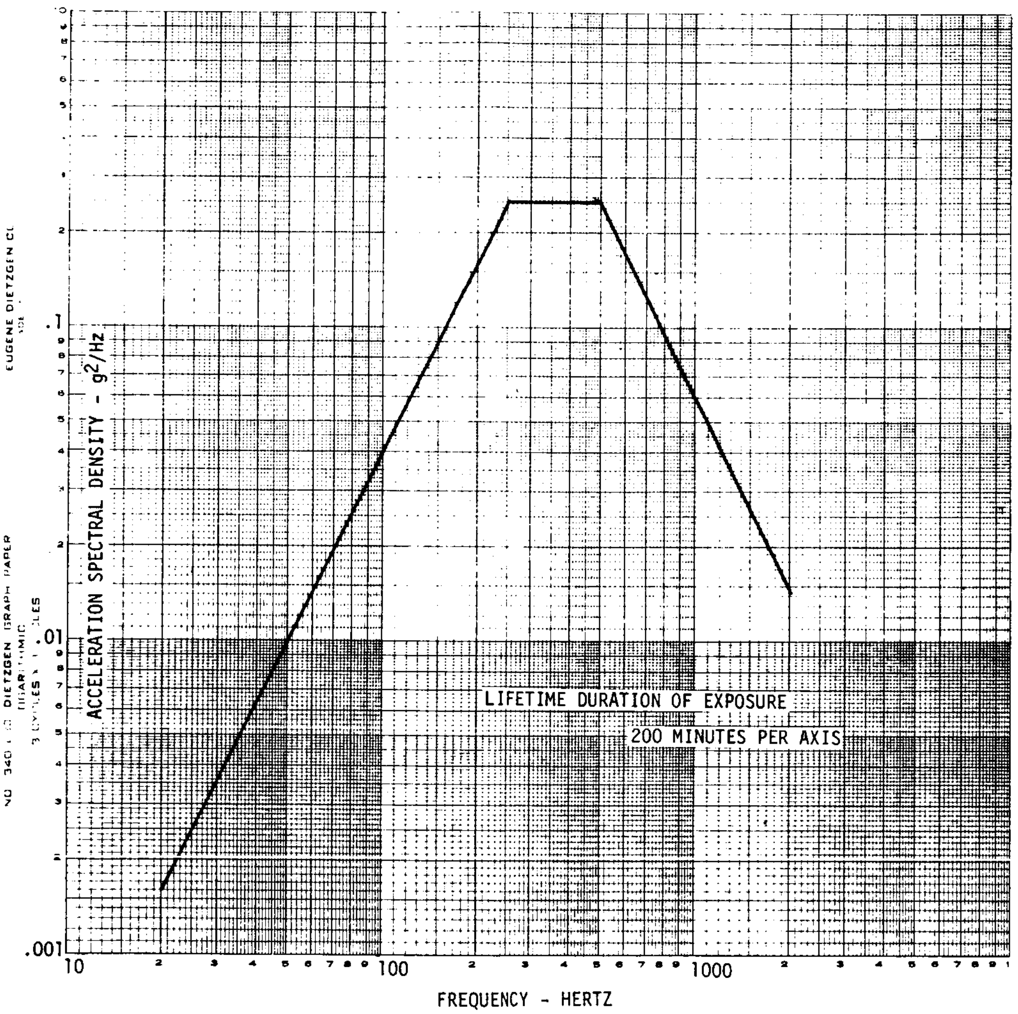

FIGURE 7 EVA EQUIPMENT VIBRATION ENVIRONMENT

APPENDIX I

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